1. Manufacturing Process and Grades

1・1 Manufacturing Process

Polycarbonate is polyester generally formed by condensation of dihydroxy compound and carbonic acid.

Such polyester was known from long ago, but it has not been considered as an intersting resin industrially, because the degree of polymerization was not sufficiently high and the melting point was low.

In 1956, Dr. Schnell reported that thermoplastic resin having superior heat resisting property could be obtained by using aromatic compounds as the dihydroxy compound and this attracted the attention of the industry.

The following two methods are known as the manufacturing process.

One of these is the so-called solution method or the solvent method, in which gasified phosgene is blown into a suspension of an alkaline aqueous solution of dihydroxy compund and an organic solvent (for example, methylene chloride) to obtain polycarbonate of high degree of polymerization.

The feature of this method is that products up to a high degree of polymerization can be obtained, but on the other hand, the process of refining and separating the resin dissolved in the organic solvent becomes necessary.

The second method is called the ester substitution method or the melt method, in which polycarbonate is obtained by polycondensation of dihydroxy compund and diester carbonate compound in the melted state.The feature of this method is that the product can be obtained as a uniform molten substance, but it is difficult to obtain products with high degree of polymerization.

2. Physical Constants

2・1 Average Molecular Weight

As a general rule, the molecular weight of a polymer is distributed in a certain range and in view of this, it is possible to obtain only the average value. Consequently, the average molecular weight gives the different result depending on the average method. For example, there are the weight average molecular weight (Mw), number average molecular weight (Mn) and the viscosity average molecular weight (Mv) and generally, the following relation exists among these,

$Mn < Mv < Mw$

The properties of polymers such as mechanical strength and melt viscosity can be inferred, as a general rule, from the average molecular weight and in view of this, it is first necessary to know the average molecular weight.

Determination of the molecular weight of Iupilon / NOVAREX is carried out by the viscosity method, as indicated below.

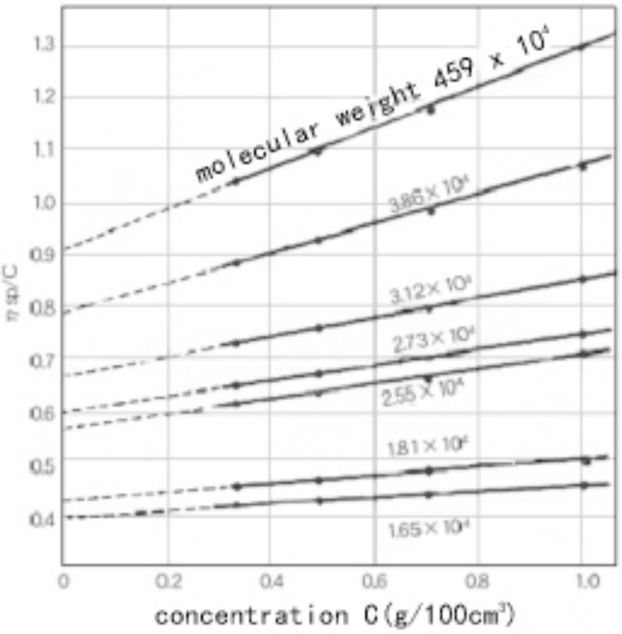


Fig. 2・1－1 Relation between concentration of Iupilon / NOVAREX and reduced viscosity
(Solvent is methylene chloride, temperature 20℃)

1g of the resin is weighed accurately and dissolved uniformly in 100 cm3 of methylene chloride and the specific viscosity η_{sp} is determined with an Oswald viscosimeter. Then the concentration is changed variously and specific viscosity determined similarly, and the concentration c versus η_{sp}/c is plotted on a graph and

$$[\eta] = \lim_{c \to 0} \eta_{sp}/c \qquad (2.1\text{-}1)$$

is obtained. $[\eta]$ is called the intrinsic viscosity and the relation between $[\eta]$ and average molecular weight was expressed by Schnell as follows:

$$[\eta] = 1.23 * 10^{-4} M^{0.83} \qquad (2.1\text{-}2)$$

The η_{sp}/c and c relation of Iupilon / NOVAREX is shown in Fig. 2・1－1. These straight lines satisfy the relation of

$$\eta_{sp}/c = [\eta] + k' [\eta]^2 c \qquad (2.1\text{-}3)$$

k' does not depend on the molecular weight but is a constant of

$$k' = 0.45$$

Consequently, if η_{sp} at a certain concentration c is determined, it will be possible to obtain $[\eta]$ by calculation as k' is known. This method is called the one point determination method.

Fig. 2.1-2 shows Equation 2.1-2 when indicated graphically.

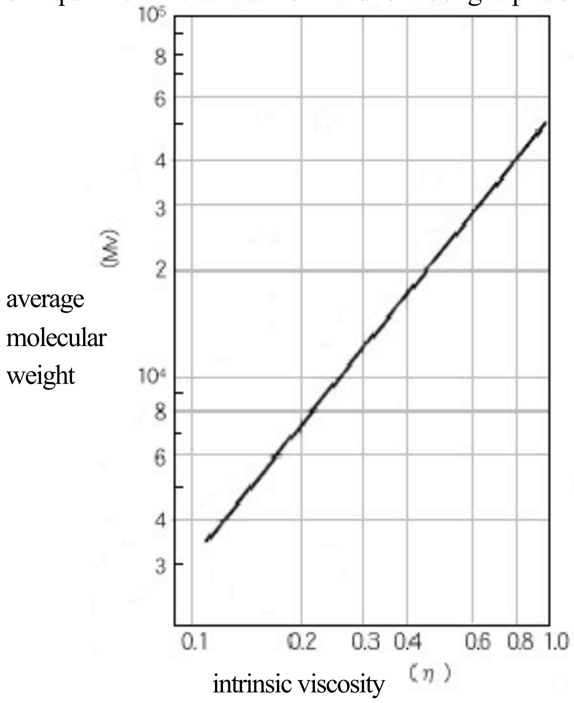


Fig. 2・1－2 Graph showing the intrinsic viscosity – average molecular weight relation

A lot of reports concerning the solution physical properties of polycarbonate have been presented.

The summary of the relation between 〔η〕 and various molecular weights in these reports is indicated in Table 2・1-1.

Table 2・1－1　Related equation of 〔η〕 and average molecular weight

Name	Temperature	Measuring method	Solvent	Related equation
H. Schnell	20℃	Osmometry	MC	$[\eta]=1.23\times10^{-4}Mn^{0.83}$
C. V. Schulz	20℃	Ultracentrifugation	THF	$[\eta]=3.99\times10^{-2}Mw^{0.70}$
	“	“	MC	
	“‘	Light scattering method	MC	) $[\eta]=1・11\times10^{-2}Mw^{0.82}$
GeneralElectric	25℃	Light scattering method	Dioxane	$[\eta]=5.54\times10^{-4}Mw^{0.67}$
S. H. Merrill		Ebulliometry	Chlorobenzene	$[\eta]=5.7\times10^{-45}Mn^{1.01}$
A. Chirico	20℃	Light scattering method	Chloroform	$[\eta]=0.277\times Mw^{0.5}$
Kouda		Freezing point depression method	Dioxane	$[\eta]=1.33\times10^{-4}Mn^{0.96}$
Teramachi	20℃	Light scattering method	Dioxane	$[\eta]=9.15\times10^{-4}Mw^{0.60}$
	“	“	THF	$[\eta]=1.0\times10^{-1}Mw^{0.57}$
	“	Osmometry	“	$[\eta]=2.3\times10^{-2}Mw^{0.76}$
G. Sitaramaiah	25℃	Light scattering method	EC	$[\eta]=2.04\times10^{-4}Mw^{0.76}$
	“	“	TCE	$[\eta]=1.34\times10^{-4}Mw^{0.82}$
	“	“	THF	$[\eta]=3.89\times10^{-4}Mw^{0.70}$
	“	“	Chloroform	$[\eta]=1.20\times10^{-4}Mw^{0.82}$

Notes　MC : Methylene chloride,　THF : Tetrahydrofuran
EC : Ethylene chloride,　TCE : Tetrachloroethane

2・2 Molecular Weight Distribution

After the average molecular weight has been obtained, it is next important to know the average value of its distribution. The characteristics of the resin differ considerably even if the average molecular weight is the same, depending on its distribution.

There are many methods for determining molecular weight distribution but all of these are based on the principle of fractionating according to each molecular weight (although actually there is a range) by utilizing the difference in solubility, sedimentation velocity, absorbability etc. and obtaining the weight % of each.

The result when Iupilon film (molecular weight 3.2×10^4, film thickness 0.08mm) is dissolved gradually in a mixed solvent of acetone-methylene chloride and fractionated is shown in Fig. 2.2-1.
The degree of polymerization in the figure was obtained by dividing the molecular weight by the molecular weight of the repeating unit of polymerization (= 254).

Also, the result of measuring the molecular weight distribution of Iupilon by the GPC method was shown in Fig. 2.2-2.

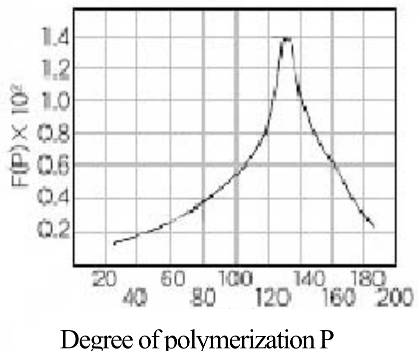
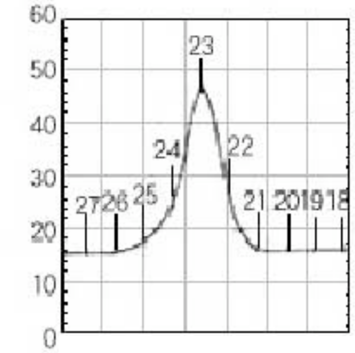


Fig. 2・2−1
Molecular weight distribution of



Equipment Waters. ALC/GPC301 Type

Sample Iupilon 2.5mg	Injecting time 120sec
Concentration 1/8w/v%	Column temperature 22℃
Solvent THF	Column10^5,10^4,10^3,10^2,nm
Flow rate 10cm3/min	STYRAGEN

Fig. 2・2−2
Molecular weight distribution of Iupilon by GPC

It can be seen from this figure that the molecular weight distribution of Iupilon is very symmetrical, and moreover the width is narrow, U(Mw / Mn-1) value is in the range of 1~2.

2・3 Specific Gravity and Crystallinity

The specific gravity is as shown in Table 2.3-1.

Table 2・3−1

300℃	1. 06	Injection molded product	1. 19
250℃	1. 10	Pellet	1. 19
Complete crystal	1. 30	Compression molded product	1. 19
Casting film	1. 22		

If polycarbonate is heat-treated at temperature below Tg (glass transition point), hardening phenomenon is observed, but as shown in Fig. 2.3-3, almost no change is observed in the X-ray diffraction, it is thought that crystallization does not take place. However, various measurements such as electronic microscope, differential thermal analysis, specific gravity measurement etc. are done recently, and the area where the packing is highly concentrated at least locally (it is thought that there is a considerably high arrangement though the growth to crystal is not observed) is indicated.

The change in density by heat treatment is shown in Fig. 2.3-1.

In addition, the change in specific gravity when plasticizer is added to Iupilon is shown in Fig. 2.3-2.

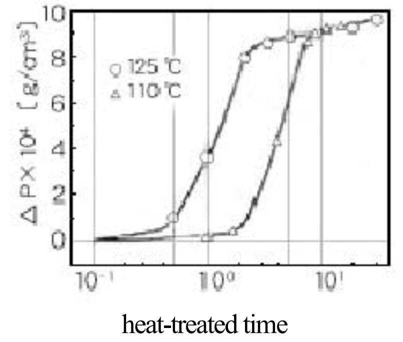


Fig. 2・3－1　Change in density
by heat treatment

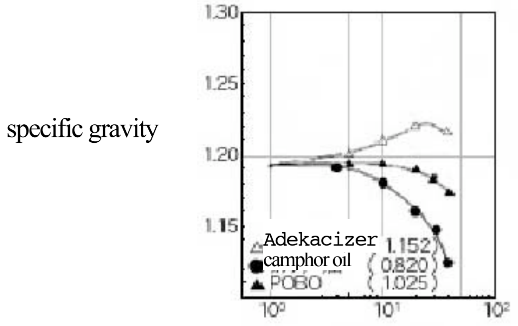


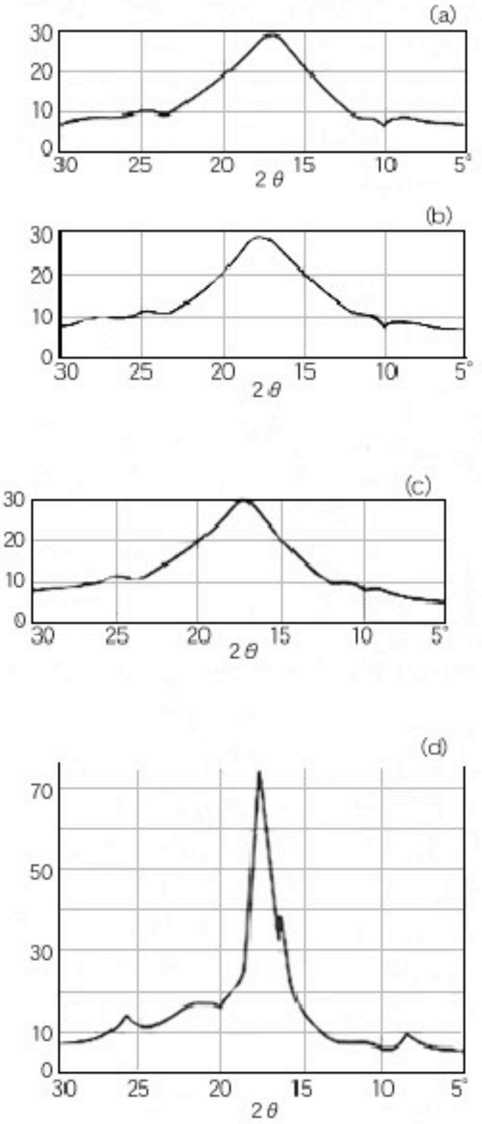
Fig. 2・3－2　Change in specific gravity
by adding plasticizer

A comparison with other commercial resins is shown in Table 2・3－2.

Table　2・3－2　Specific gravity of various polymers

Polymer	Average specific gravity	Polymer	Average specific gravity
Teflon	2. 2	High impact strength polystyrene（HIPS）	1. 06
Chlorofluoroethylene	2. 1	Polystyrene	1. 06
Polyacetal	1. 4	Polyphenylene ether（PPE）	1. 06
Rubber degenerated vinyl chloride	1. 35	High impact strength ABS	1. 05
Cellulose acetate	1. 3	ABS	1. 05
Polysulphone	1. 24	High density polyethylene	0. 95
Cellulose butyrate	1. 2	Medium density polyethylene	0. 93
Cellulose propionate	1. 2	Low density polyethylene	0. 92
Polycarbonate	1. 2	Polypropylene	0. 90
Nylon	1. 14	Glass fiber reinforced nylon	1. 33
Ethyl cellulose	1. 13		
Acryl（PMMA）	1. 12	Glass fiber reinforced polystyrene	1. 3

In general, the crystallization of Iupilon / NOVAREX does not take place easily. As shown in Fig.2・3－3, the temperature for crystallization is around 190℃but the induced time of 130-170 hours for crystallization is necessary even at this temperature, and the achievement of crystallinity is about 30%. This relation is indicated in Fig. 2・3－4 and it is clear that there is an influence of the molecular weight. In addition, the relation between the treatment temperature and the crystallinity is shown in Fig. 2・3－5.



a）Molten state at 280℃　　c）Heat treated 20 days at 130℃
b）Glass state at 20℃　　d）Heat treated 8 days at 190℃

Fig. 2・3−3　Strength X-ray diffraction of Iupilon

When a suitable organic substance is added to Iupilon, the induced time for crystallization is shortened. As shown in Fig. 2.3-6, the induced time for crystallization of a sample containing 10% of diphenyl ether is about 5 hours. However, when the molecular weight is 5.0×10^4 or more, the crystal is not observed at 190℃, 20hrs. In addition, when a small amount of nucleic agent is added to this, the crystallization takes place rapidly as shown in Fig. 2.3-7. The tendency to such a crystallization decreases rapidly when the molecular weight is $Mv=4.0\times10^4$ or more due to the influence of the molecular weight as shown in Fig. 2.3-8.

A similar crystallization phenomenon is also observed by the sedimentation from the dilute solution and the immersion to the swelling agent etc. for example, when making casting film excluding heat treatment. The degree of crystallization when Iupilon of various molecular weights is immersed in toluene is shown in Fig. 2.3-9. The degree of crystallization which can be reached does not change greatly when the molecular weight is $Mv=4.0\times10^4$ or more. The ketone, aldehyde, ether, and ester play the role as swelling agents.

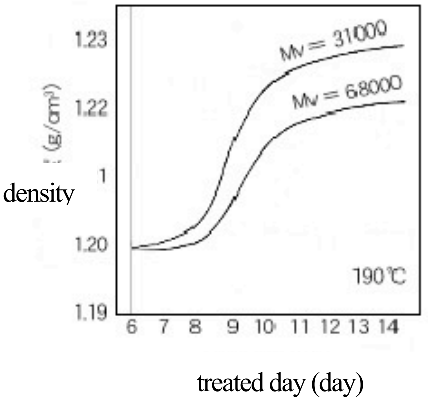


Fig. 2・3−4 Change in density by heat treatment

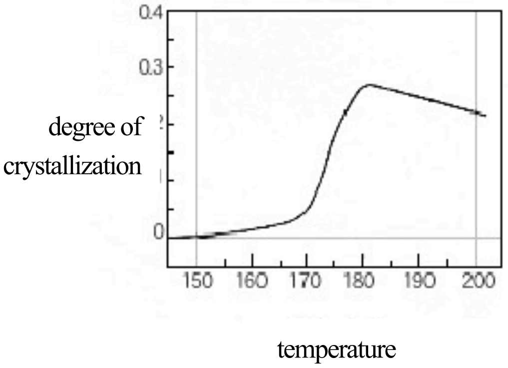


Fig. 2・3−5 Relation between temperature and degree of crystallization

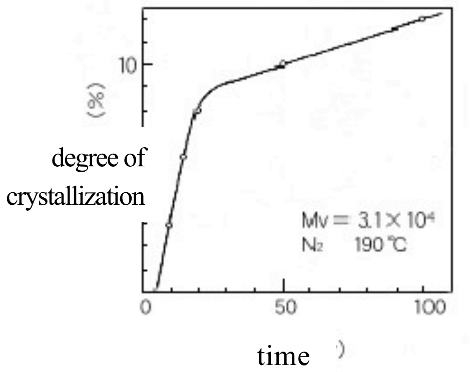


Fig. 2・3−6 Degree of crystallization of sample containing diphenyl ether

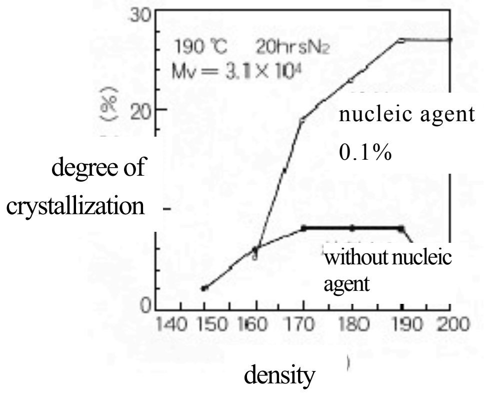


Fig. 2・3−7 Relation between temperature and degree of crystallization of sample containing diphenyl ether

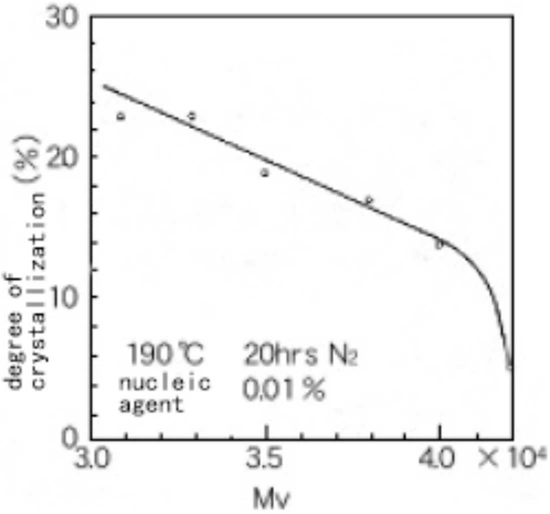


Fig. 2・3－8 Influence of molecular weight on degree of crystallization of sample containing diphenyl ether

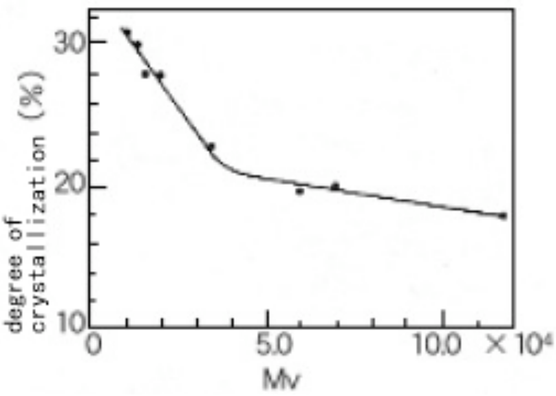


Fig. 2・3－9 Saturated degree of crystallization of sample immersed in toluene

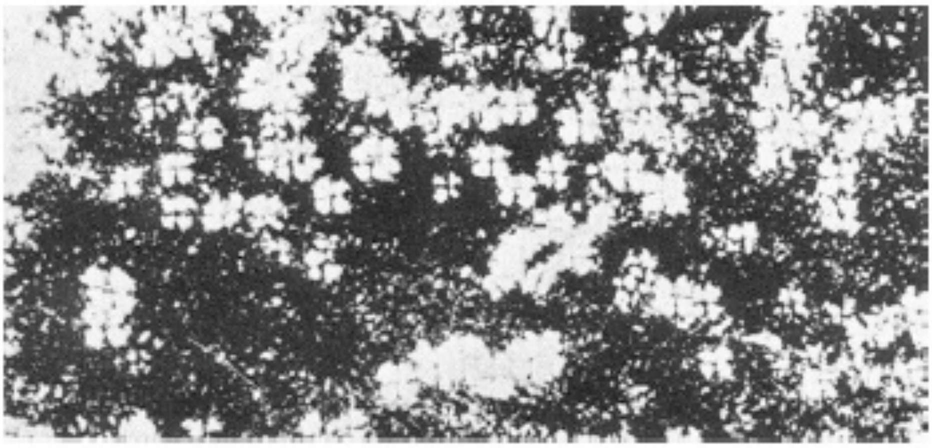


Fig. 2・3－10 Spherical crystals of Iupilon / NOVAREX (Polarizing microscope photograph)

In almost all cases, the crystals of Iupilon / NOVAREX are spherical as shown in Fig. 2.3-10. Iupilon / NOVAREX molding material may be actually considered as being amorphous and it can be considered that there is almost no change in performance by crystallization in the molding process and in the environment in which it is used.

2・4　Melt Viscosity

Iupilon / NOVAREX has a higher melt viscosity than other resins.

Also, the melt viscosity is influenced by pressure and temperature but in case of Iupilon/NOVAREX the effect of temperature is larger than that of pressure.

The results obtained when determined by the Koka type flow tester are shown in Fig. 2・4−1, 2・4−2, 2・4−3 and 2・4−4.

The slope of the straight line obtained from Fig. 2・4−2 is −0.2 for Iupilon / NOVAREX and this is very small when compared with acetyloid, polystyrene and polyethylene. That is, the melt viscosity of Iupilon / NOVAREX does not receive almost any effect of pressure. Consequently, it is possible to treat Iupilon / NOVAREX practically as a Newton liquid at a high temperature.

When fluid activation energy is obtained from the slope of the straight lines of Fig. 2・4−4, this is 26-29 kcal/mol in case of Iupilon / NOVAREX, which is the next largest after the 47 kcal/mol of acetyloid. It can therefore be seen that the decrease in melt viscosity with rise in temperature is very large.

When the relation between the molecular weight of Iupilon / NOVAREX and melt viscosity is consolidated with Flory's relative equation, it becomes as shown in Fig. 2・4−5, and when the constant of Flory's relative equation is obtained from the slope of the straight line and the ordinate intercept, the following relative equation is obtained.

$$\log Q = 2.39 - 0.023M^{1/2}$$

Also, when the relation between the molecular weight of Iupilon / NOVAREX and melt viscosity is consolidated with Fox's relative equation, $\log \eta = a \log Mw - B$, it becomes as shown in Table. 2・4−1.

Table 2・4−1　Relation between melt viscosity and molecular weight

Name	Sample	Determination conditions		α	B
		τ	Temperature		
J. Bojarski	Separated sample U=1.2～1.3	0	280℃	5.52	20.6
		10^4	"	5.15	19.0
		10^5	"	4.46	16.0
		2×10^5	"	4.27	15.2
J. Bojarski	Unseparated	0	280℃	3.02	9.6
G. F. Baumann	Unseparated	2.6×10^5	302℃	3.23	10.73
Mitsubishi Gas Chemical Company, Inc.	Unseparated	40×10^5	280℃	4.5	15.9

τ unit: dPa（dyne／cm^2）

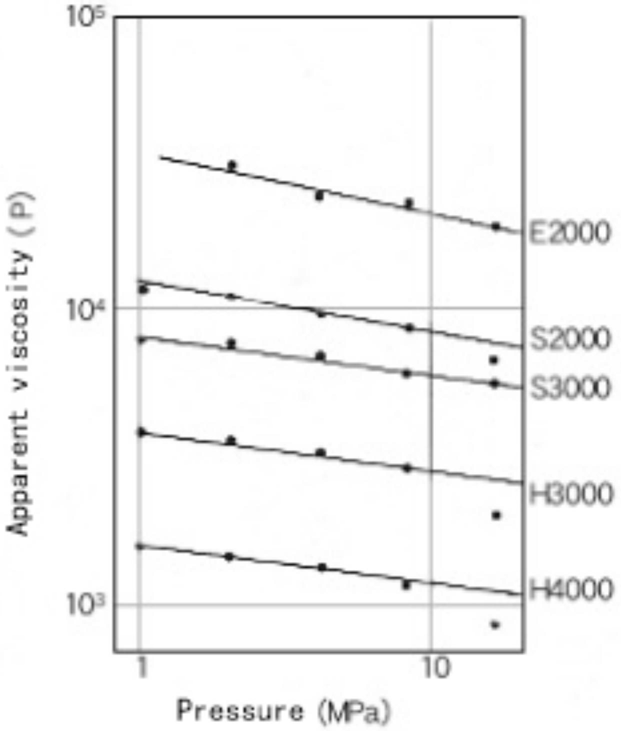


Fig. 2・4－1　Relation between melt viscosity and pressure of Iupil
(Koka type flow tester, temperature 280℃, nozzle φ 1×10mmL）

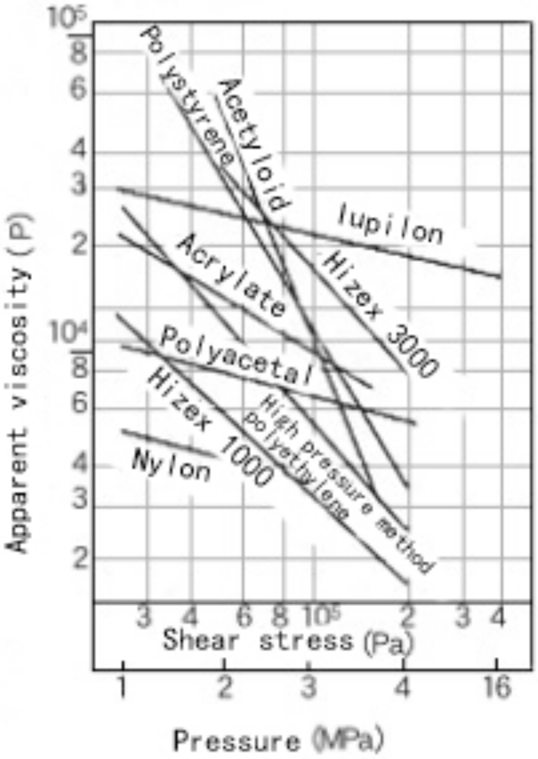


Fig. 2・4－2 Relation between melt viscosity and pressure of various resins
(Koka type flow tester, nozzle φ 1×10mmL, temperature 280℃ for Iupilon,
180℃ for acetyloid, 230℃ for nylon and acrylate, and 200℃ for all others）

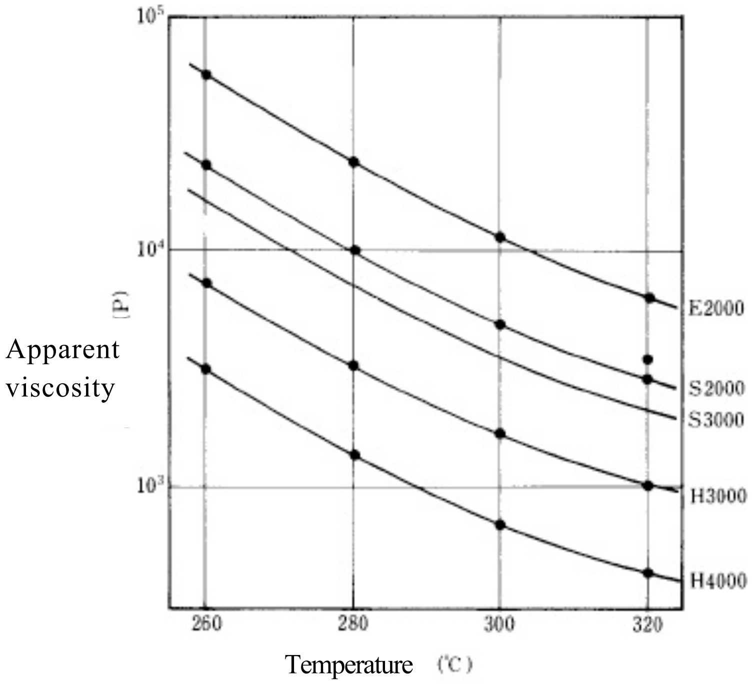


Fig. 2・4－3　Relation between melt viscosity and temperature of Iupilon
(Koka type flow tester, pressure 3.9 MPa , nozzle ϕ 1×10mmL)

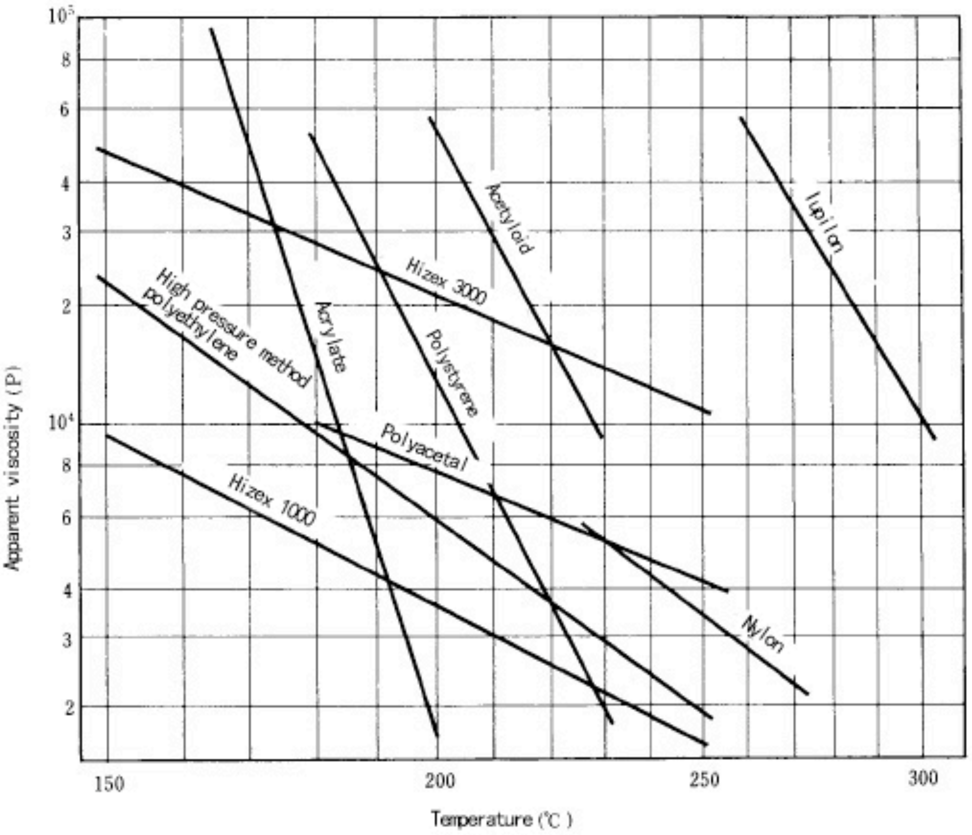


Fig. 2・4－4
Relation between melt viscosity and temperature of various resins
(Koka type flow tester, nozzle ϕ 1×10mmL, pressure 0.98MPa for nylon, 3.9Mpa for others)

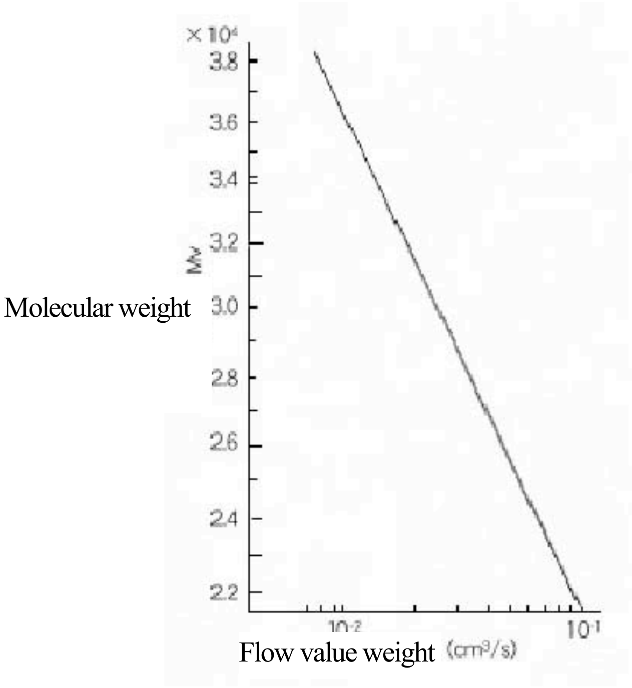


Fig. 2・4－5 Relation between molecular weight and flow value of Iupilon / NOVAREX (Koka type flow tester, nozzle ϕ 1×10mmL, pressure 15.7 MPa 〔160kgf/cm^2, temp. 280℃〕)

"Flow value" is used as a measure for expressing the moldability of Iupilon / NOVAREX and this "flow value" is measured with Koka type flow tester. The determination conditions are 280℃, 15.7 Mpa (160kgf/cm^2) and nozzle ϕ 1×10mmL. The determination value is shown in cm^3/s. The melt viscosity is calculated from this value by the conventional method and this "flow value" is sufficient as a practical comparison value. As the method for indicating "flow value", this is indicated as 3.0 when the determination value is 3.0 x 10^{-2}cm^3/s.

	Unit	Conditions	E－2000 7027A	S2000 7025A	S3000 7022A
Melt volume index	cm^3／10min	IS0－1133 300℃ 1. 2kg	4～6	9～12	12～19
Flow value (Q value)	10^{-2}・cm^3／s	280℃ 15. 7MPa (160 kgf/cm^2)	0. 5～3	3～7	5～12

Note : Representative values of measuring values based on test method.

3 . Mechanical Properties

3・1 Tensile Strength

The stress-strain curve when tension is applied to ASTM-D638 type 1 test piece of Iupilon / NOVAREX at a strain velocity of 5mm/min is shown in Fig. 3・1—1.

The following are the values of Iupilon / NOVAREX at room temperature.

$\sigma_y = 54 \sim 64$ Mpa ($550 \sim 650$kgf/cm^2)

$\sigma_b = 59 \sim 69$ Mpa ($600 \sim 700$kgf/cm^2)

$\varepsilon_y = 6 \sim 8\%$

$\varepsilon_b = 90 \sim 140\%$

The temperature characteristic of the tensile yield stress of Iupilon / NOVAREX is shown in Fig. 3・1—2.

.The influence of strain velocity is shown in Fig. 3・1—3, 4.

The relation with the tensile yield stress at a low strain velocity can be displayed by the straight line as shown in Fig. 3・1—3, but increases rapidly at a high strain velocity as shown in Fig. 3・1—4 .

The relation between molecular weight and tensile yield stress is shown in Fig. 3・1—5, 6, 7.

Iupilon / NOVAREX becomes t brittle break completely at Mv = 15000.

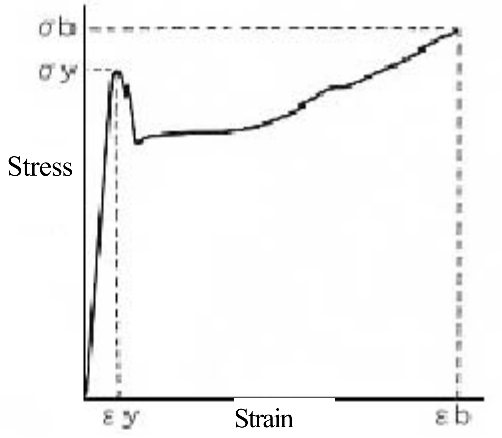


Fig. 3.1-1 Stress-Strain curve of Iupilon / NOVAREX

σ y Yield stress σ b Breaking stress
ε y Elongation at yield ε b Elongation at break

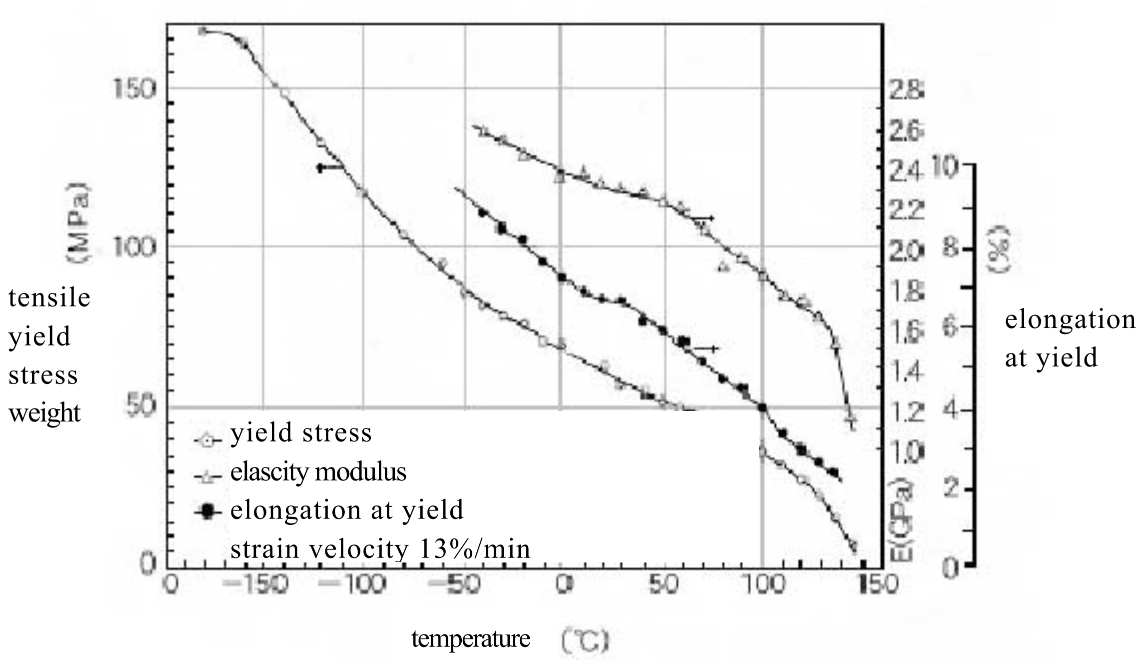


Fig. 3・1—2 Temperature characteristic curve of tensile yield stress

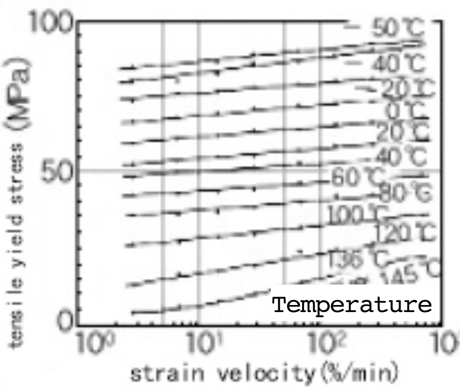


Fig. 3・1－3
Relation between strain velocity and tensile yield stress

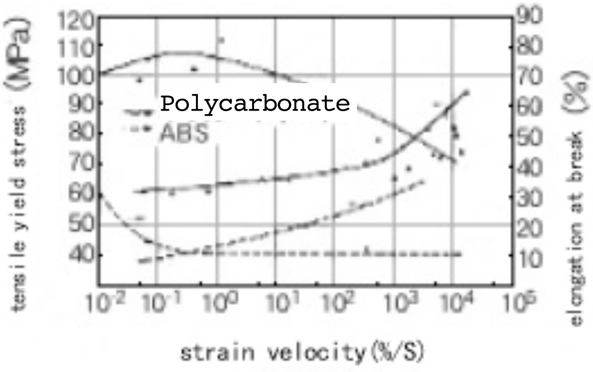


Fig. 3・1－4 Relation between strain velocity and tensile yield stress and break elongation(literature value)

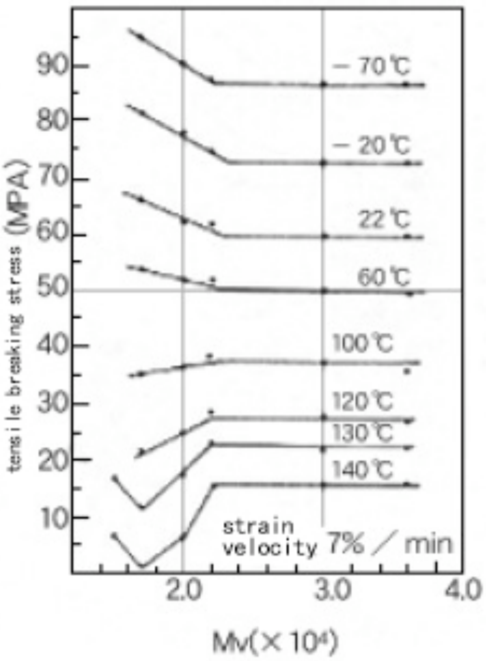


Fig. 3・1－5
Relation between molecular weight
and tensile yield stress

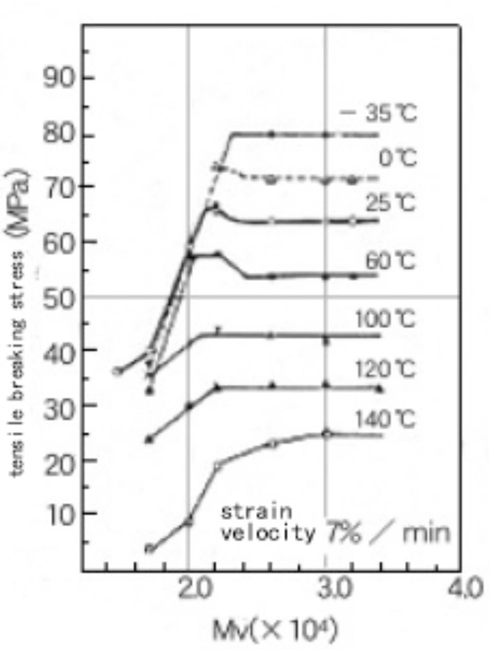


Fig. 3・1－6
Relation between molecular weight and tensile breaking stress

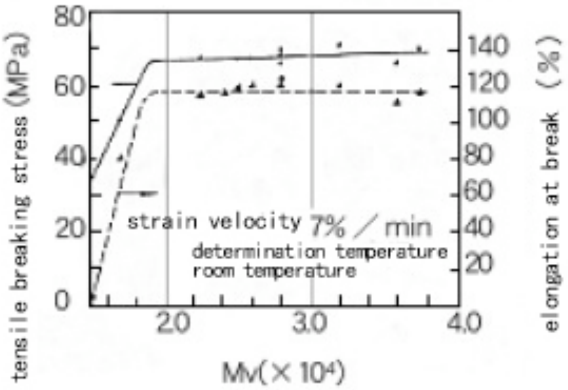


Fig. 3・1－7　Relation between molecular weight and tensile properties

When Iupilon / NOVAREX is heat-treated, the hardening phenomenon is observed as shown in Fig. 3・1－8, 9. The yield strength rises even at 50℃ but causes the hardening earliest at 130-150℃ as shown in Fig. 3・1-10.

The comparison of mechanical properties of Iupilon / NOVAREX with other resisns is as shown in Fig. 3・1－11, 12, 13 and 14.

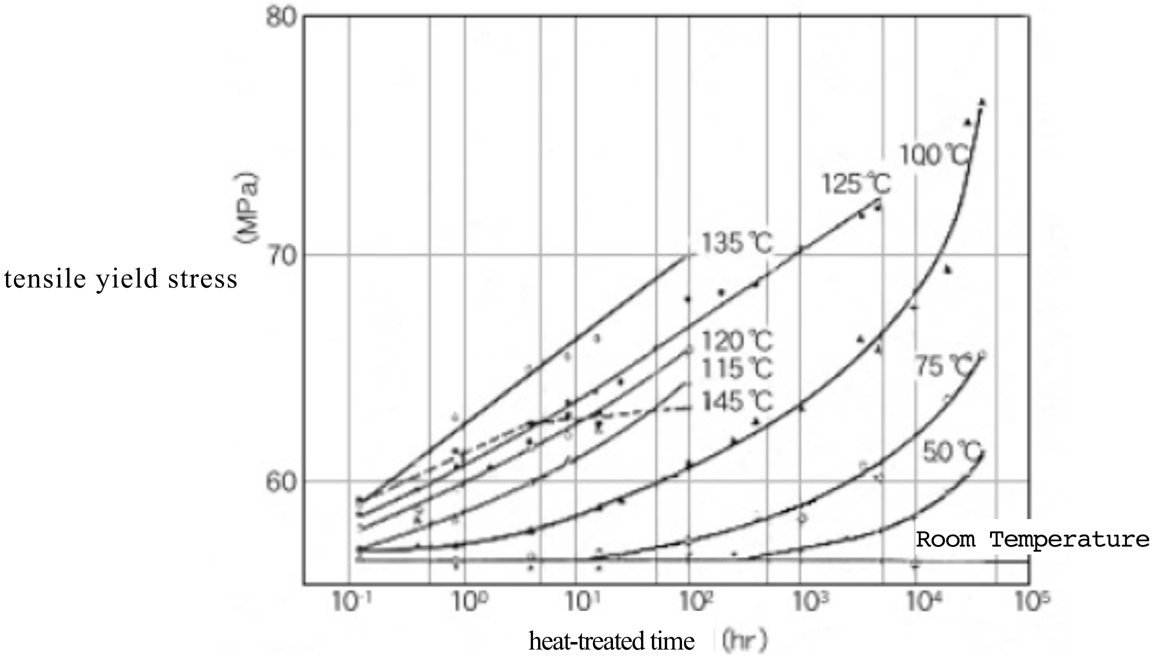


Fig. 3・1－8 Change in tensile yield stress by heat treatment
(strain velocity 7%/min)

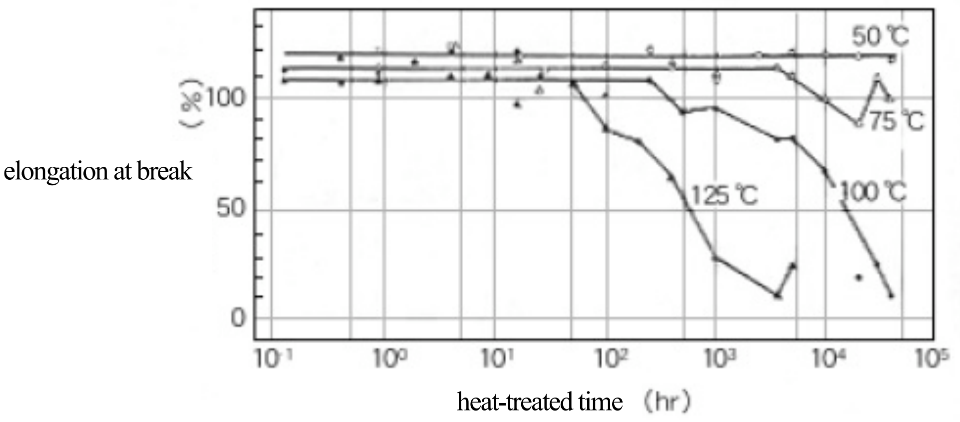


Fig. 3・1－9 Change in elongation at break by heat treatment
(strain velocity 7%/min, room temperature)

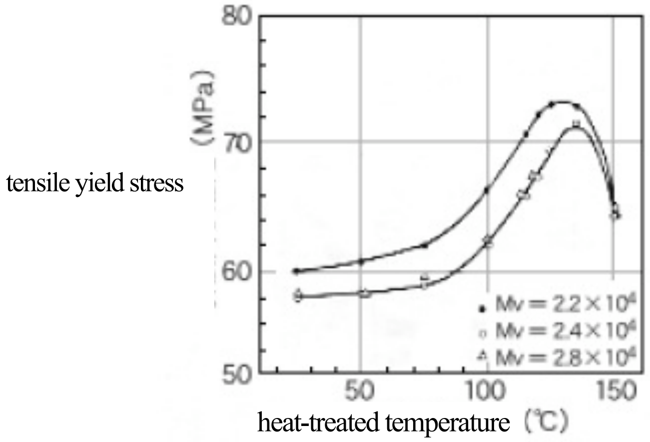


Fig. 3・1－10　Change in tensile yield stress
(strain velocity 7%/min, heat-treated time 100 hours)

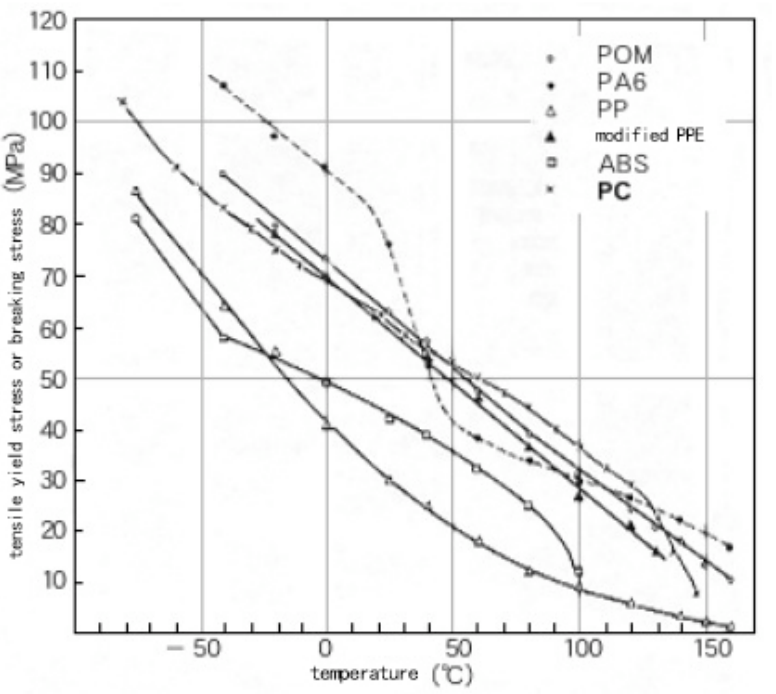


Fig. 3・1－11　Relation of Iupilon / NOVAREX with other resins

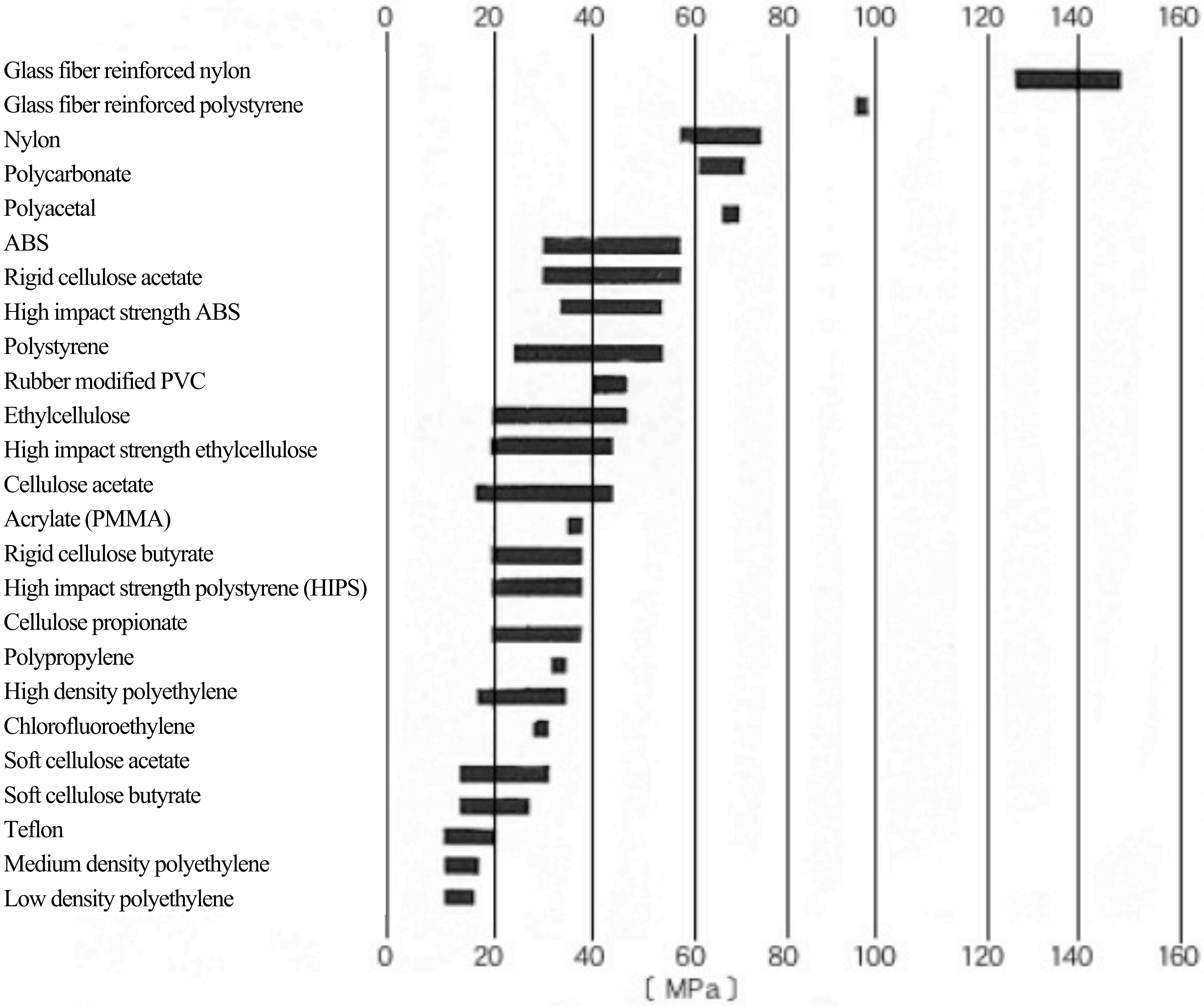


Fig.　3・1－12　Breaking stress of various resins

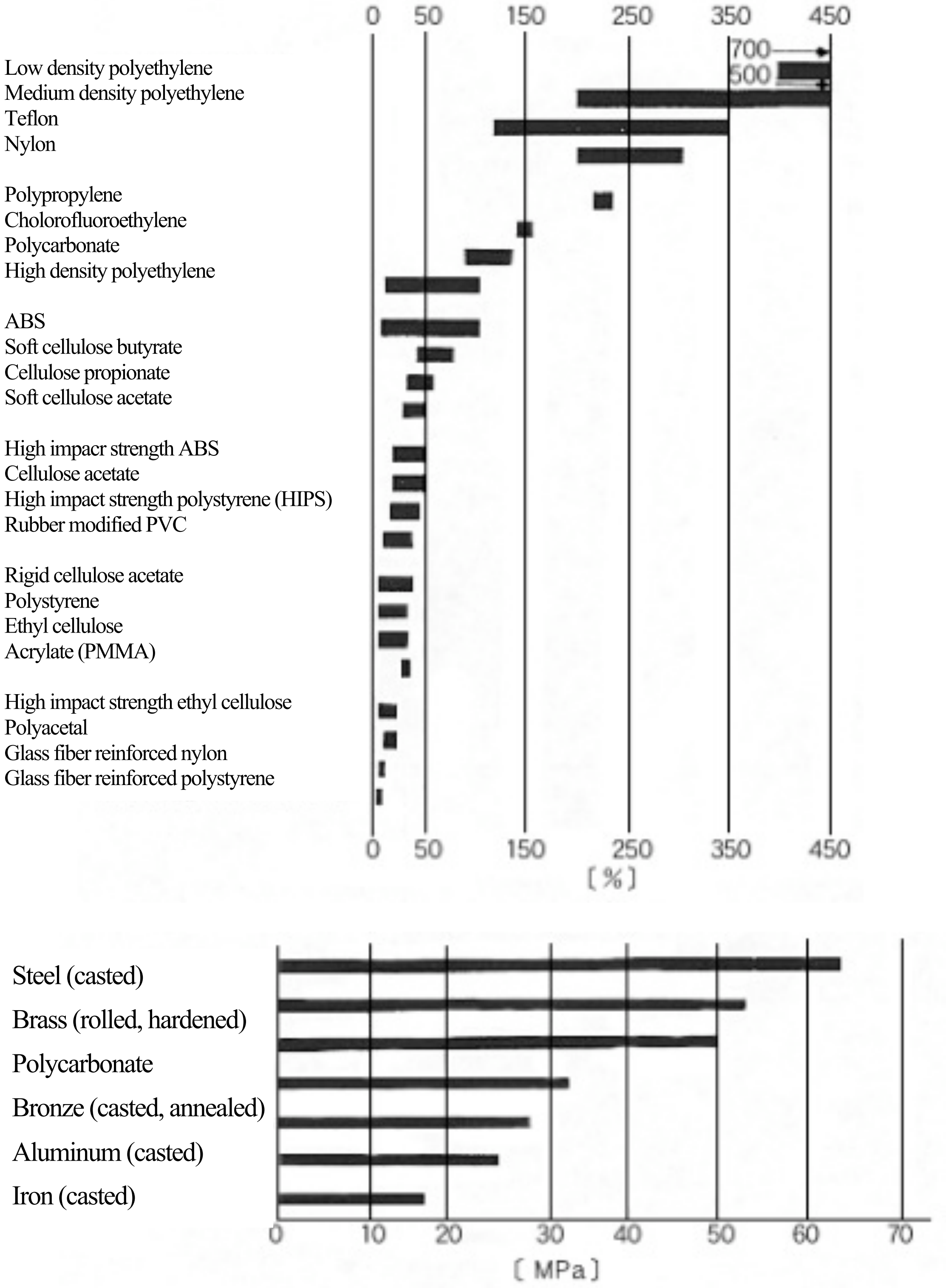


Fig. 3・1－14 Tensile strength per unit weight of Polycarbonate and metals

3・2　Compressive Strength

The compressive strength of Iupilon / NOVAREX is 74~88Mpa (750 ~ 900kgf/cm^2) and modulus of elasticity is 1.7 ~1.9Mpa (17×10^3 ～19×10^3kgf/cm^2). Also, the rate of deformation at yield is 8 ~ 10%.

The relation between compressive strength, modulus of elasticity and temperature of Iupilon / NOVAREX is shown in Fig. 3・2—1.

The Poisson's ratio of Iupilon / NOVAREX is 0.38.

A comparison with other resins is shown in Table 3・2—1.

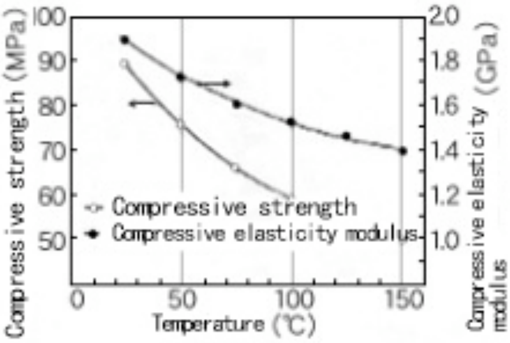


Fig. 3・2—1
Change in temperature of compressive strength and modulus of elasticity

Table 3・2—1

Name	Compressive Strength (ASTM—D695) MPa（kgf／cm^2）	Name	Compressive Strength (ASTM—D695) MPa（kgf／cm^2）
Polycarbonate	76. 5（780）	Rigid cellulose butyrate	53. 0～154（540～1570）
Rubber modified PVC	35. 3～62. 8（360～640）	Glass fiber reinforced polystyrene	91. 2～108（930～1100）
High impact strength polystyrene（HIPS）	28. 4～62. 8（290～640）	Cellulose acetate	105～176（1070～1790）
Cellulose propionate	49. 0～154（500～1570）	Glass fiber reinforced nylon	112（1140）
High impact strength ethyl cellulose	69. 6～245（710～2500）	Rigid cellulose acetate	133～253（1360～2580）
Ethyl cellulose	69. 6～245（710～2500）	Modified acrylate（MMA）	44. 1～98. 1（450～1000）
Soft cellulose acetate	91. 2～140（930～1430）	Polyacetal	36. 3（370）
Soft cellulose butyrate	53. 0～154（540～1570）	Polypropylene	59. 8～69. 6（610～710）

3・3　Flexural Strength

The flexural strength of Iupilon / NOVAREX is 80～90Mpa (820～920kgf／cm^2) and the flexural modulus of elasticity is 2. 26GPa （23000kgf／cm^2） . Also, it does not break when bent to an angle of 80 ～90° .

The temperature characteristics and the influence of molecular weight on flexural strength are shown in Fig. 3・3—1, 2 and 3, respectively.

The change in flexural strength by heat treatment is shown in Fig. 3・3—4.

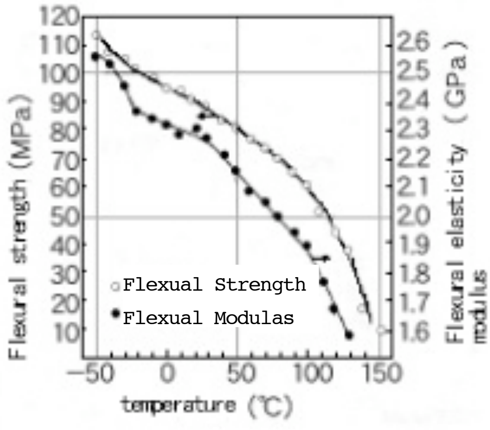


Fig. 3・3−1 Temperature characteristics of flexural strength

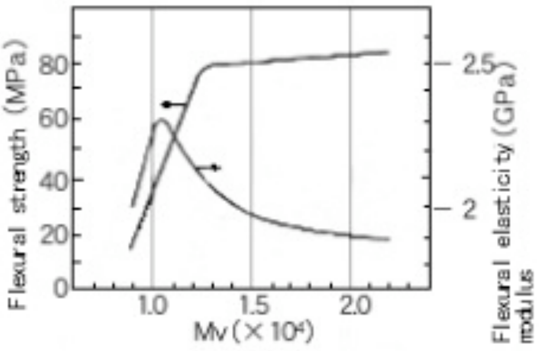


Fig. 3・3−2 Influence of average molecular weight on flexural strength (literature)

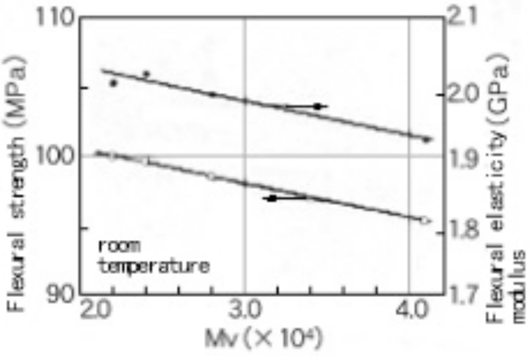


Fig. 3・3−3 Influence of average molecular weight on flexural strength

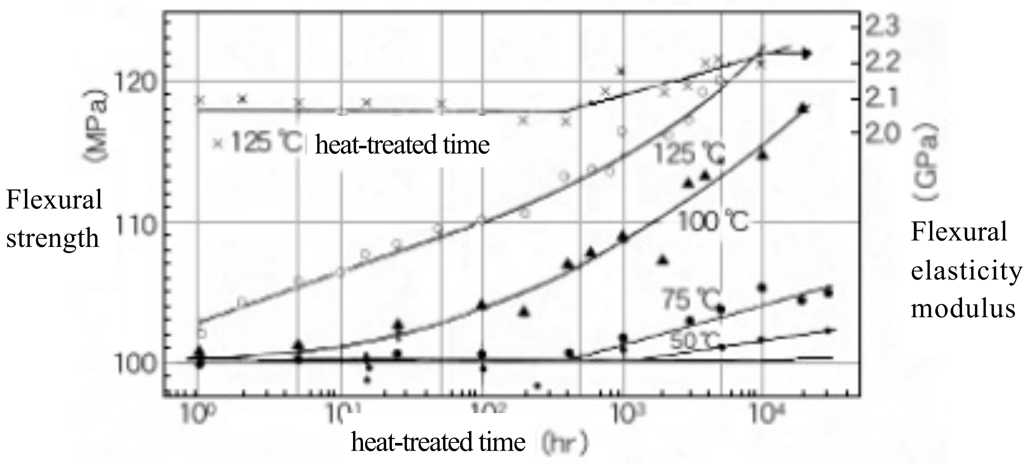


Fig. 3・3−4
Change in flexural strength by heat treatment
（Mv＝2．8×10⁴）

A comparison with other resins is shown in Fig. 3・3－5 and Table 3・3－1.

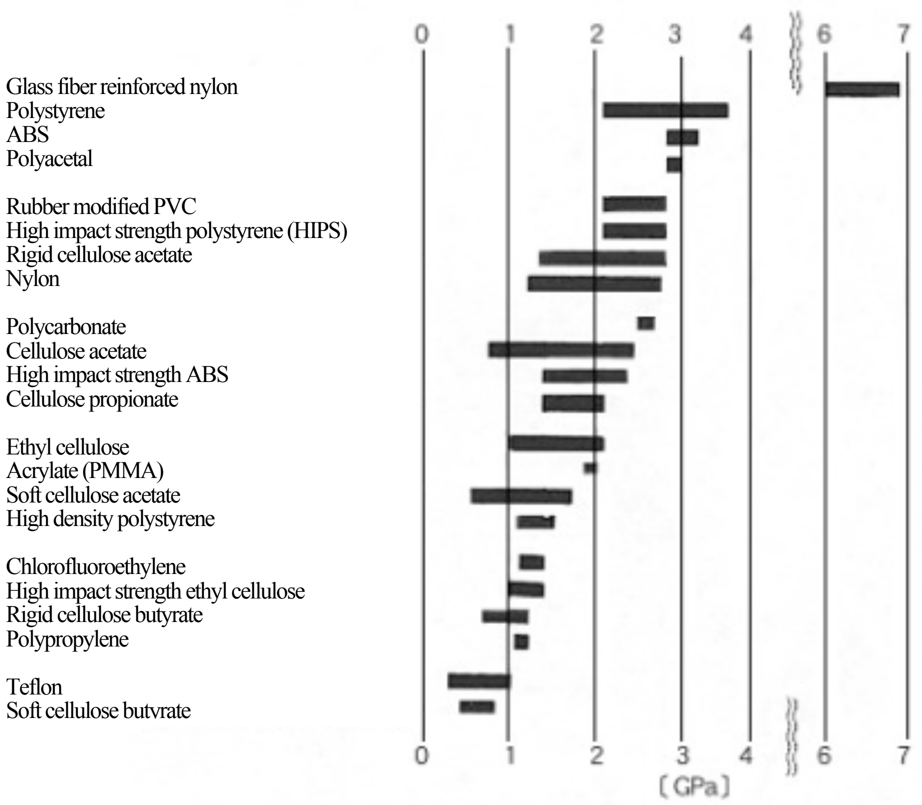


Fig. 3・3－5 Flexural modulus of elasticity of various resins

Table 3・3－1

Name	Flexural strength（ASTM－D790）MPa（kgf／cm^2）	Name	Flexural strength（ASTM－D790）MPa（kgf／cm^2）
Polycarbonate	80.4～90.2^d（820～920^d）	Teflon	NB
High impact strength polystyrene（HIPS）	NB	Chlorofluoroethylene	NB
Cellulose propionate	27.5～64.7^d（280～660^d）	Glass fiber reinforced nylon	140～155（1430～1580）
High impact strength ABS	48.1～55.9^d（490～570）	Polystyrene	NB
High impact strength ethylene cellulose	27.5～42.2（280～430）	ABS	53.0～77.5（540～790）
Ethyl cellulose	27.5～70.6（280～720）	Rigid cellulose acetate	41.2～70.6^d（420～720^d）
Soft cellulose acetate	18.6～50.0^d（190～510^d）	Nylon	NB
Soft cellulose butyrate	17.7～36.3^d（180～370^d）	Acrylate（PMMA）	62.8～91.2（640～930）
Rigid cellulose butyrate	27.5～55.9（280～570）	Polyacetal	100（1020）
Glass fiber reinforced polystyrene	113（1150）	Polypropylene	56.9（580）
Cellulose acetate	25.5～58.8^d（260～600^d）		

NB＝no break, d＝yield stress

3・4 Impact strength

The impact values of Iupilon / NOVAREX are as follows:

Izod method, with notch (thickness 3.2mm) ASTM D256	740~1000J/m	(75~102kgf.cm/cm)
Izod method, with notch (thickness 6.4mm) ASTM D256	98~250J/m	(10~25kgf.cm/cm)
Izod method, without notch (thickness 3.2mm)	＞3700J/m	(＞380kgf.cm/cm)
Charpy method, with notch (thickness 6.4mm) ASTM D256	15~59kJ/m^2	(15~60kgf.cm/cm^2)
Tensile impact method (thickness3.2mm) ASTMD1822	690 ~ 880 kJ/m^2	(700~900 kgf.cm/cm^2)(L)
(thickness 1.6mm) ASTMD1822	1100~1500 kJ/m^2	(1100~1500 kgf.cm/cm^2)(L)

Falling ball method (thickness 3.2mm)

Tip of ball 12.7mmR, circular support 50.8mmϕ	240~310J	(24~32kgf.m)
Tip of ball 20.0mmR, circular support 90 mmϕ	170~230J	(17~23kgf.m)

The temperature characteristic of the impact value of Iupilon / NOVAREX is shown in Fig. 3・4—1 and 3・4—2. The Izod impact values and the falling ball impact values indicate brittle break at the temperature around -50℃, and below -70℃, respectively. (The temperature that break shifts from ductility to brittleness is called the transition temperature). Also, as shown in Fig. 3・4—3, the brittle break is generated when the thickness becomes a constant value but the specific thickness and the state of change depend on the kind of the impact.

The influence of molecular weight on impact values are shown in Fig. 3・4—4, 5 and 6.

In the temperature region where the ductile rupture is shown, the molecular weight which shows its maximum in any test method exists.

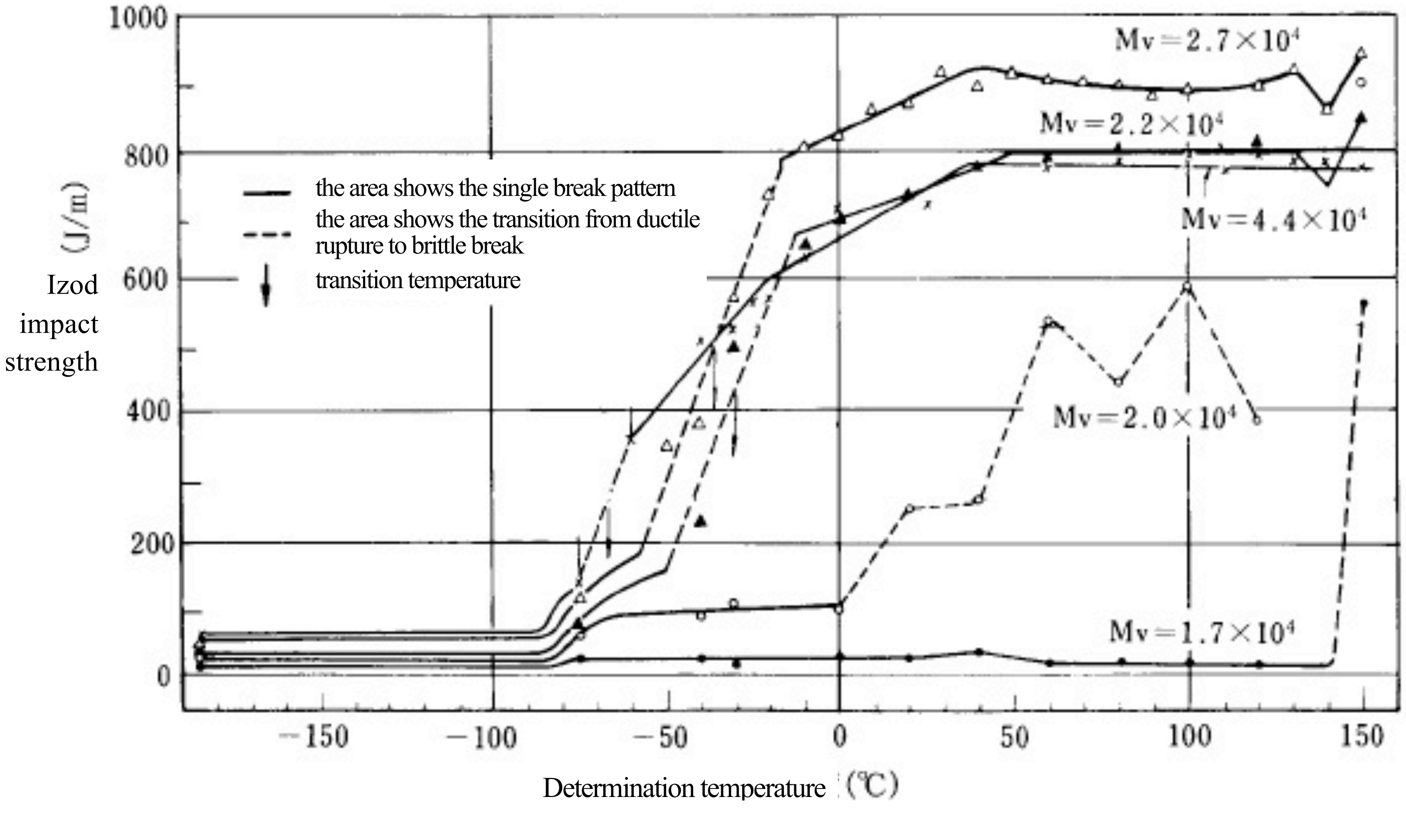


Fig. 3・4—1 Izod impact strength-temperature characteristics

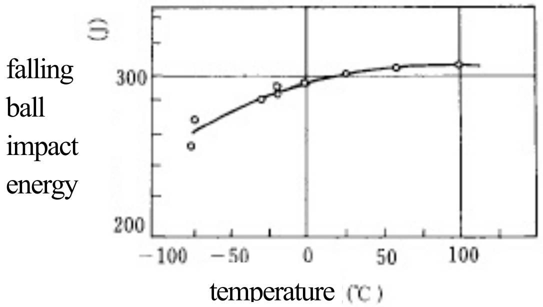


Fig. 3・4−2 Change in temperature of falling ball impact
(circular disc with thickness of 2mm)

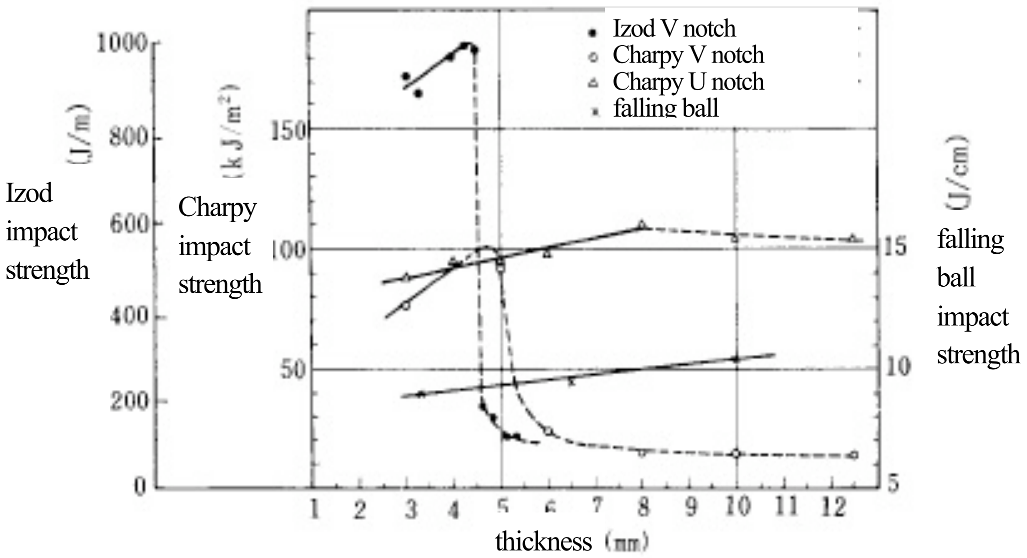


Fig. 3・4−3 Change in impact values by sample thickness (room temperature)
−ductile rupture ……brittle break

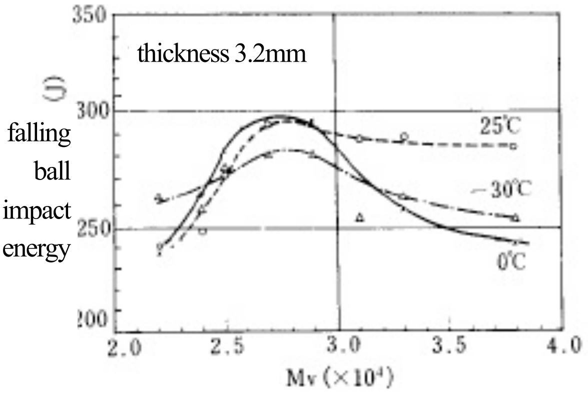


Fig. 3・4−4 Relation between molecular weight and falling ball impact energy

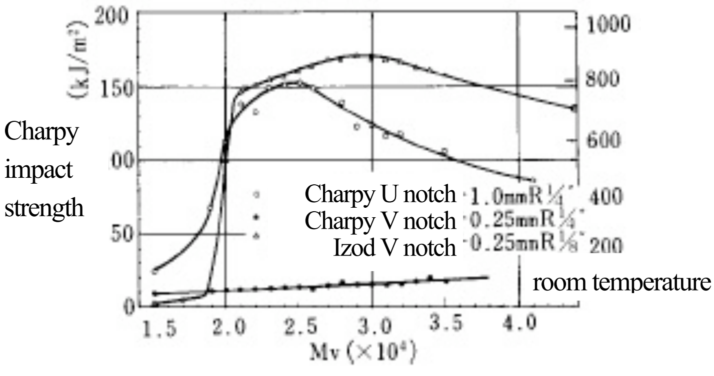


Fig. 3・4−5 Relation between molecular weight and impact values

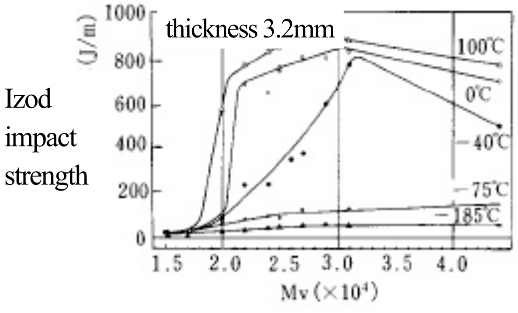
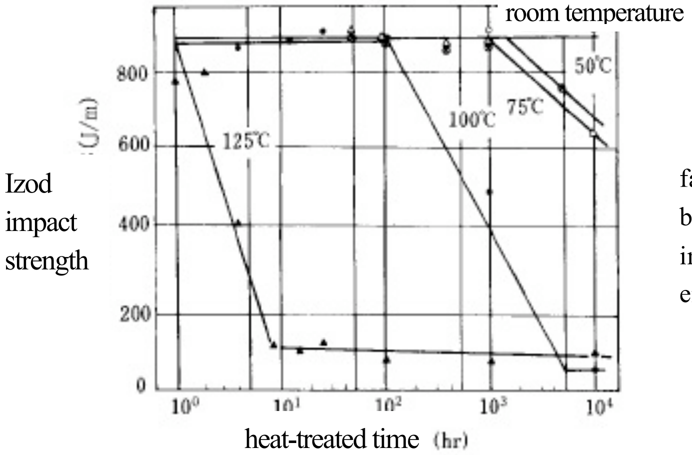


Fig. 3・4−6
Relation between molecular weight and Izod impact strength

The impact value of Iupilon / NOVAREX is known to be deteriorated by heat treatment as shown in Fig. 3. 4-7, 8, 9 and 10. It decreases rapidly in the Izod impact at 125℃, shows the deterioration even at 50℃ and 75℃ after a long time. However, it does not show the brittle break in the falling ball impact even at 125℃ and 1000hours. The change in impact character when treated at different temperature in a given time and the rapid thermal hardening at 100～140℃ are observed as shown in Fig. 3. 4-10.



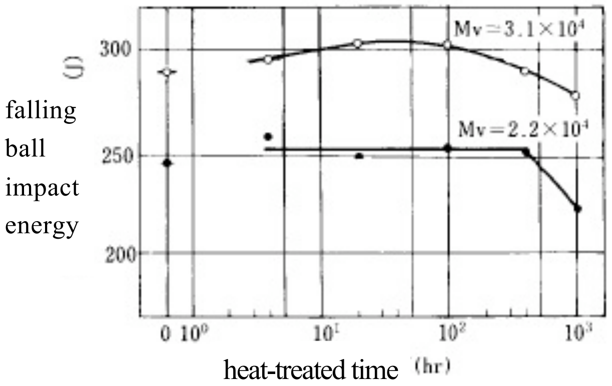
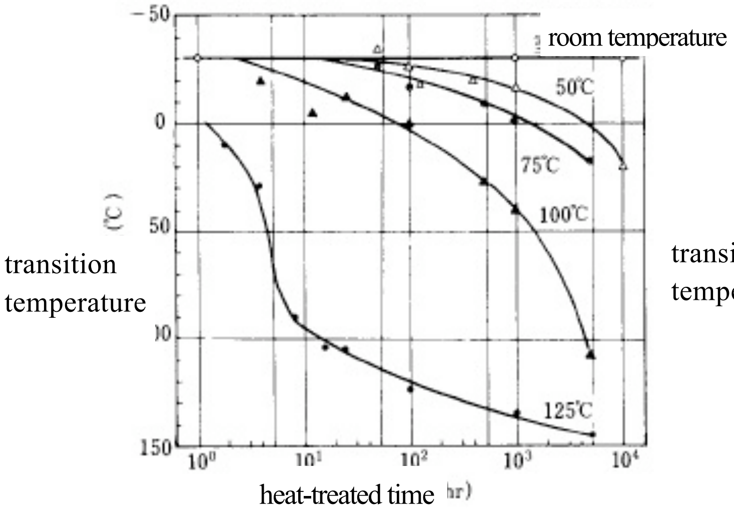


Fig. 3・4−7 Change in Izod impact strength by heat treatment

Fig. 3・4−8 Change in falling ball impact by heat treatment （125℃）



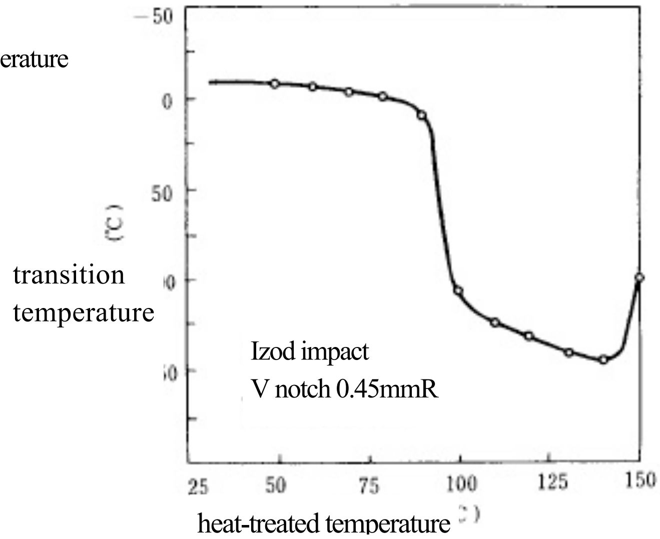
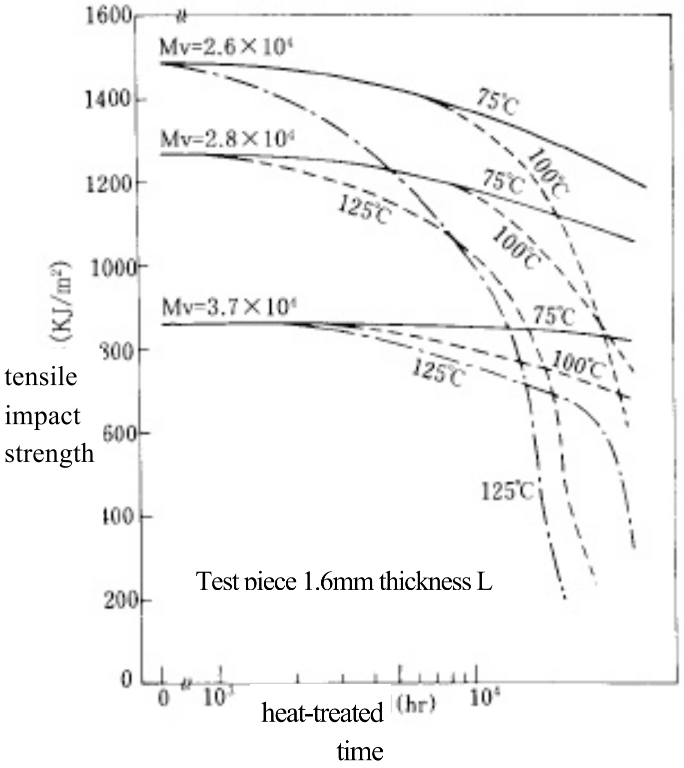


Fig. 3・4−9 Change in transition temperature by heat treatment (thickness of Izod impact test piece: 3.2mm)

Fig. 3・4−10 Effect of heat-treated temperature (treated time, 48hr, thickness 6.4mm)



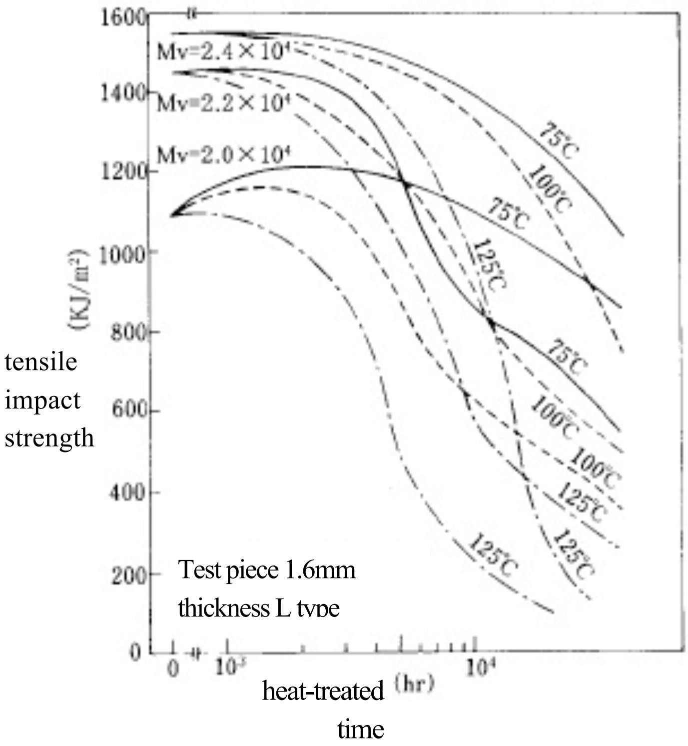


Fig. 3・4—11 Change in tensile impact strength by heat treatment — (1)

Fig. 3・4—12 Change in tensile impact strength by heat treatment — (2)

A comparison with other resins is shown in Fig. 3・4—13

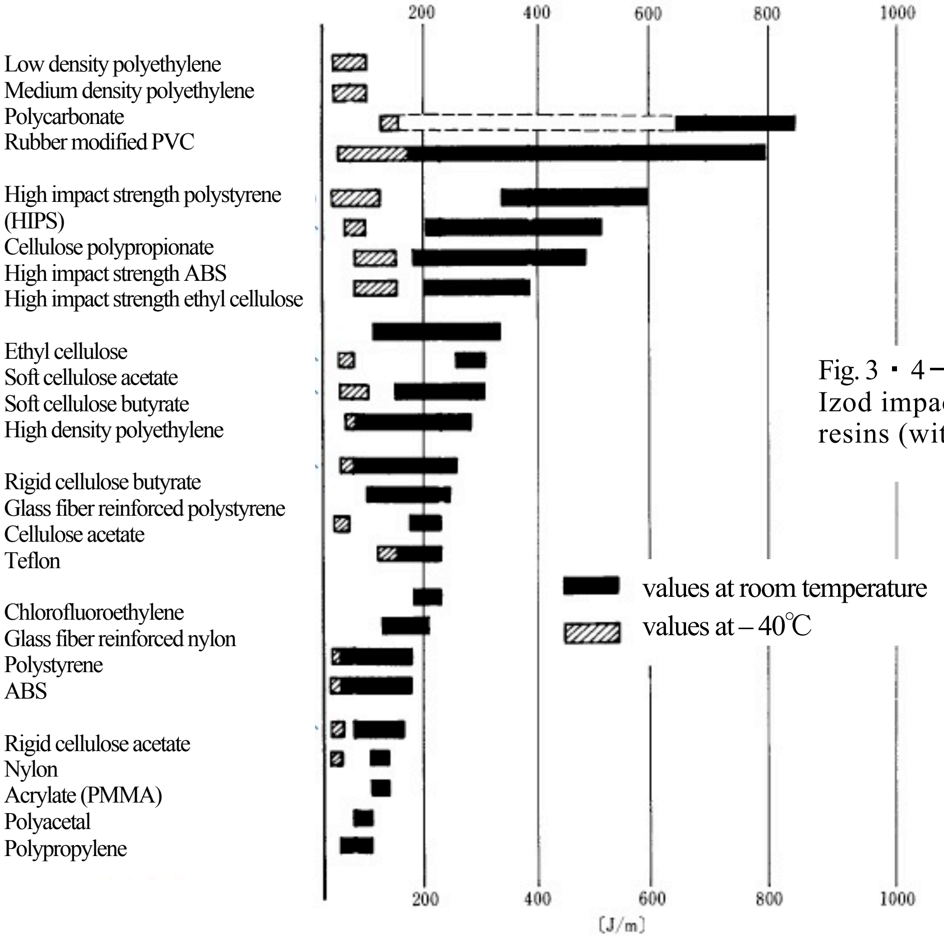


Fig. 3・4—13
Izod impact strength of various resins (with notch)

3・5　Hardness

The various hardnesses of Iupilon / NOVAREX are shown in Table 3・5−1.

Table 3・5−1　　　　Mv=2.4 x 10^4

Brinell hardness　　after 10 sec.	88.3～103MPa（900～1050kg / cm^2）
DIN53456, load 0.5kN（50kgf）　after 60 sec.	85.3～98.1MPa（870～1000kg / cm^2）
Rockwell hardness（ASTM−D785）	M60～80, L90～100, R122～124
Shore Durometer hardness	D82

The Mar resistance of Iupilon / NOVAREX is shown in Table 3・5−2.

Table 3・5−2　Surface hardness of Iupilon / NOVAREX injection molded product (ASTM-D673-44)

Mv=2.4 x 10^4

Quantity of carborundum（g）	200	400	800	1200	1600
Mar resistance（%）	90.2	82.7	72.9	58.5	56.1

Also, a comparison with other resins is shown in Table 3・5−3.

Table 3・5−3　Comparison of surface hardness of Iupilon / NOVAREX with other resins (ASTM-D673-44)

Carborundum dropping quantity 500g　　　Mv=2.4 x 10^4

Sample	Mar resistance （Ratio of luster before and after abrasion）
Iupilon / NOVAREX compression molded product	84%
Acrylate（MMA）	88%
Vinyl chloride	85%
Glass sheet（crown glass）	99%

A comparison of Rockwell hardness of Iupilon / NOVAREX with other resins is shown in Table 3・5−4.

Table 3・5−4

Name	Rockwell hardness （ASTM−D785）	Name	Rockwell hardness （ASTM−D785）
Low density polyethylene	D45 ～ 52＊	Rigid cellulose butyrate	R79 ～ 114
Medium density polyethylene	D45 ～ 65＊	Glass fiber reinforced polystyrene	M91 ～ M95
POLYCARBONATE	R122	Cellulose acetate	R68 ～ 115
Rubber modified PVC	RIO0 ～110	Chlorofluoroethylene	R112
High impact strength polystyrene (HIPS)	M30 ～ 65	Glass fiber reinforced nylon	M96 ～ MIOO
Cellulose propionate	R20 ～ 120	Polystyrene	M30 ～ 55
High impact strength ABS	R85 ～ 100	ABS	R85 ～ 118
High impact strength ethylcellulose	R70 ～ 90	Rigid cellulose acetate	RIO1 ～ 123
Ethylcellulose	R80 ～ 120	Nylon	RIO8 ～ 118
Soft cellulose acetate	R49 ～ 103	Acrylate (PMMA)	L58 ～ 59
Soft cellulose butyrate	R47 ～ 95	Polyacetal	R120（M94）
High density polyethylene	R63 ～ 70＊	Polypropylene	R85 ～ 95

＊　indicates Shore hardness

The Rockwell hardness of Iupilon / NOVAREX is changed by heat treatment as shown in Fig. 3・5－1.

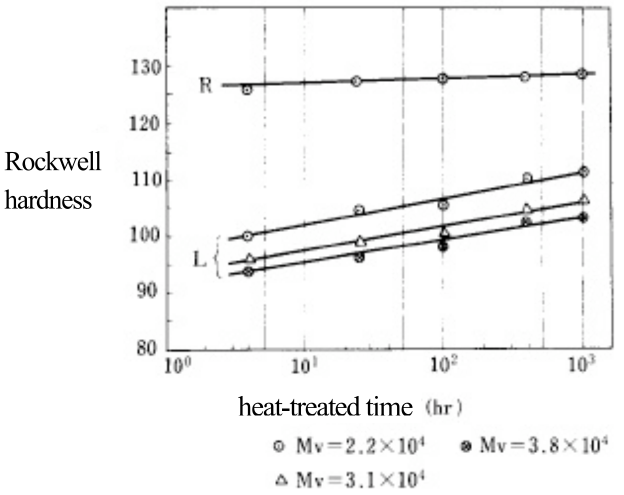


Fig. 3・5－1 Change in Rockwell hardness by heat treatment (treated temperature 125℃)

Also, the Martens scratch hardness is shown in Fig. 3・5－2.

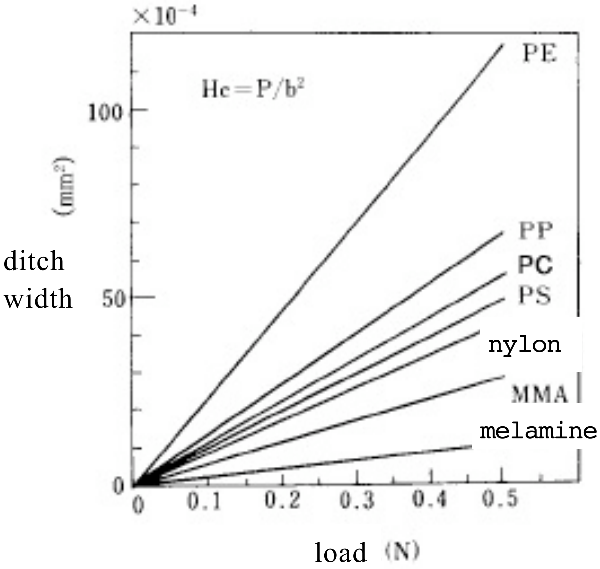


Fig. 3・5－2 Martens scratch hardness

3・6 Abrasion Resistance and Friction Characteristics

The amount of wear of Iupilon / NOVAREX by the Tabor-abrasion tester (CS－17wheel, ASTM －D1O44－56 was 13mg/1000 cycles.

Also, when the relation of

PV＝ 53.9MPa・cm／s

(PV＝ 550kgf／cm2・cm／s)

exists between the contact pressure MPa（kgf／cm2）and relative velocity (Vcm/s) in the contact abrasion between Iupilon / NOVAREX and iron, this is the limit it can withstand heat of friction. This relation is shown in Fig. 3・6－1.

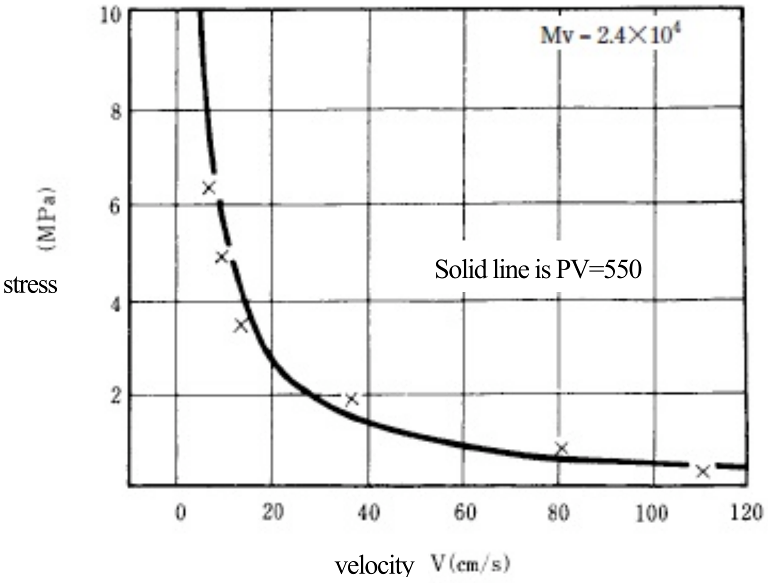


Fig. 3・6－1 PV values of Iupilon / NOVAREX

Iupilon / NOVAREX melts in the combination of P and V in the range at the upper right of the curve. In this case, the coefficient of friction was 0.5-0.6 at P=4.9MPa (50kgf/cm^2), V=0.01cm/s.

The coefficient of friction of polycarbonate is shown in Table 3・6－1 (not lubricated).

Table 3・6－1

	Low velocity (1 cm / s)	High velocity (173－202 cm / s)
Between polycarbonates	0. 24	About 2. 0
Polycarbonate on steel	0. 73	0. 82
Steel on polycarbonate	0. 35	0. 45

A comparison of abrasion （ASTM－D1242－56）between polycarbonate and other resins is shown in Fig. 3・6－2

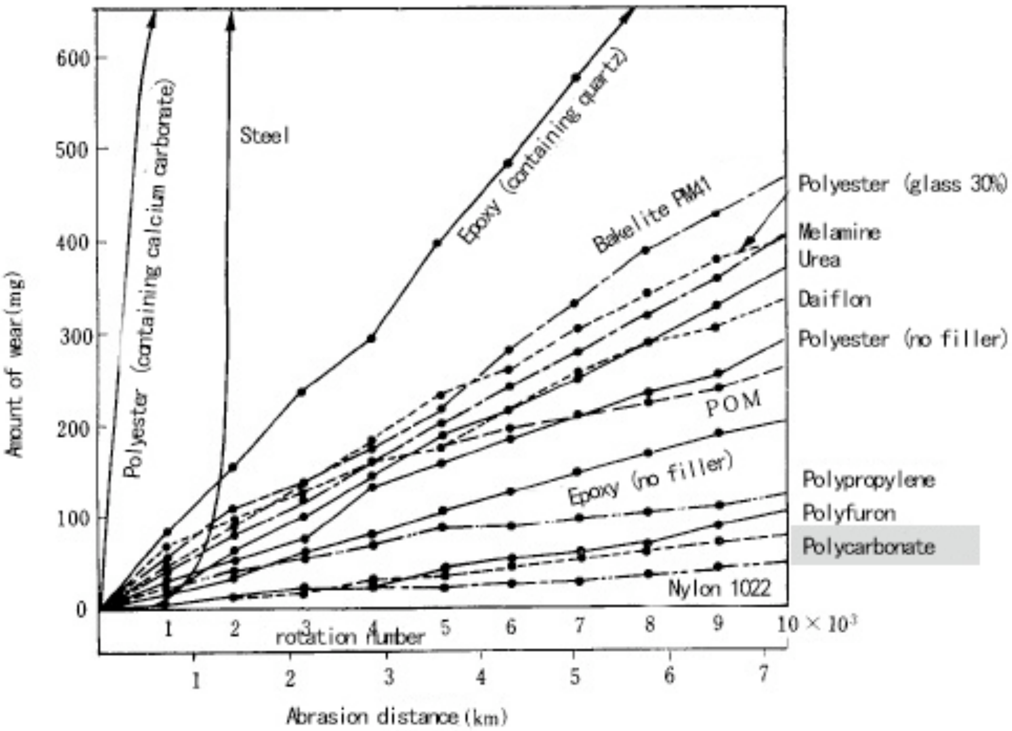


Fig. 3・6－2 Relation between abrasion distance and wear quantity of plastics
(Average abrasion velocity 0.235m/s, abrasion pressure 1.2MPa (12kgf/cm^2,
abrasive is alumina powder with average particle size of 170 mesh)

3・7 Shear Strength

The shearing yield point of Iupilon / NOVAREX is 37.3MPa (380kgf/cm^2) and the shear breaking stress is 64.7MPa (660kgf/cm^2).

The temperature characteristic of the shearing modulus of elasticity is shown in Fig. 3・7－1, from which it can be seen that Iupilon / NOVAREX is stable at high temperature and it is also stable at low temperature. As a general rule, the substance becomes brittle rapidly when the shearing modulus of elasticity (or rigidity) exceeds about 1GPa (10^{4}kgf/cm^2) but the low temperature characteristic of Iupilon / NOVAREX is better than those of other resins at -100℃ as it does not exceed 1GPa 10^{4}kgf/cm^2.

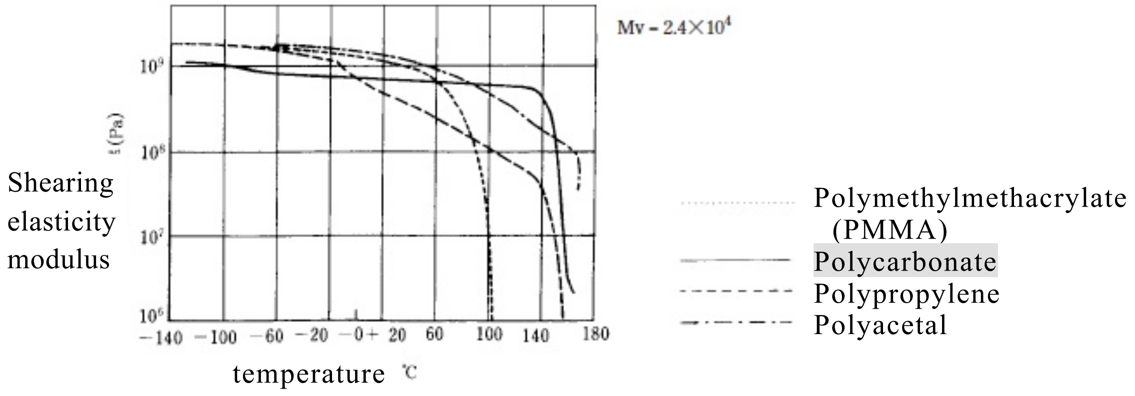


Fig. 3・7－1 Relation between temperature and shearing modulus of elasticity

3・8　Long Time Behaviour Under Load

3・8・1 Load Fatigue Characteristics

When the fatigue resistance of Iupilon / NOVAREX is examined, it becomes as shown in Fig. 3・8・1—1, 2, 3 and 4 (determination method is constant load 1000 cycle/min, room temperature). The influence of the shape of test piece at the tensile compression fatigue is shown in Fig. 3・8・1—1. The difference of the shape is obviously shown, especially the influence of cutting is shown extremely in the cutting sample. The results of tensile compression fatigue, flexural fatigue, and torsional fatigue are shown in Fig. 3・8・1—2, 3・8・1—3 and 3・8・1—4, respectively.

In any case, the fatigue resistance has improved by the increase of the molecular weight.

The influence of temperature in the rotation flexural fatigue (test piece is made by cutting) is shown in Fig. 3・8・1—5. It is observed that the fatigue limit rises drastically as the temperature decreases. Also, Fig. 3・8・1—6 shows the results of the fatigue of samples with notch.

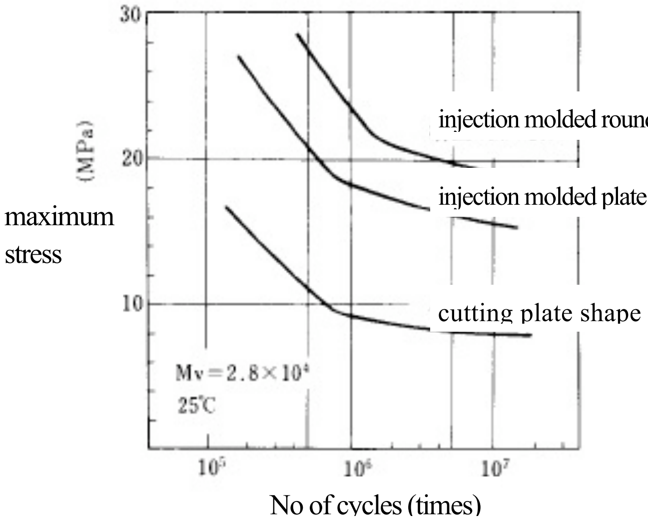


Fig. 3・8・1—1　Change in fatigue resistance by the difference of test piece shape and molding method (tensile compression)

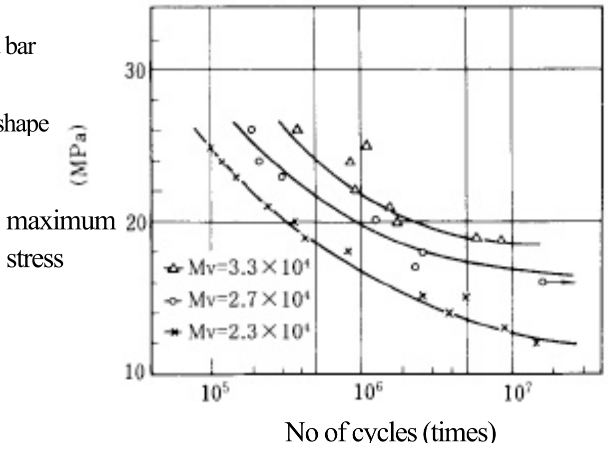


Fig. 3・8・1—2 Relation between molecular weight and fatigue resistance (tensile compression)
Injection molded piece of sample with round bar shape (determination temperature, 25℃)

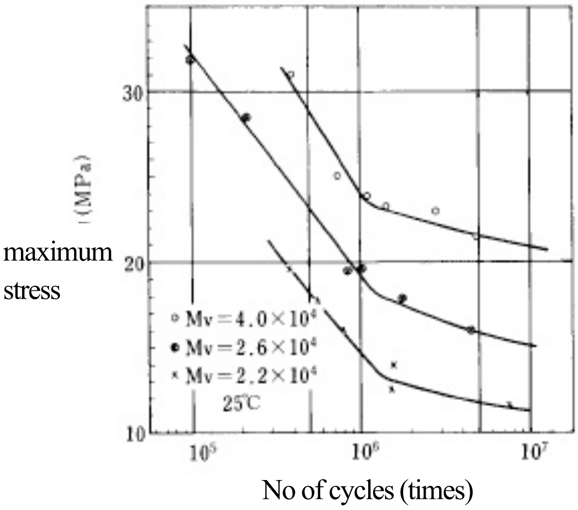


Fig. 3・8・1—3　Fatigue resistance in flexure

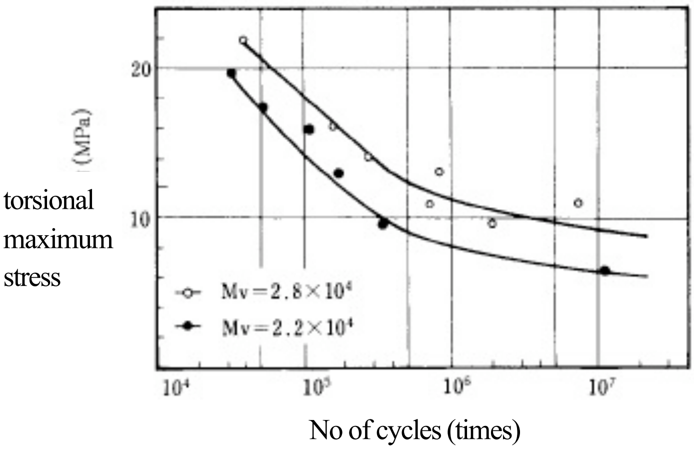


Fig. 3・8・1—4　Fatigue resistance in torsion

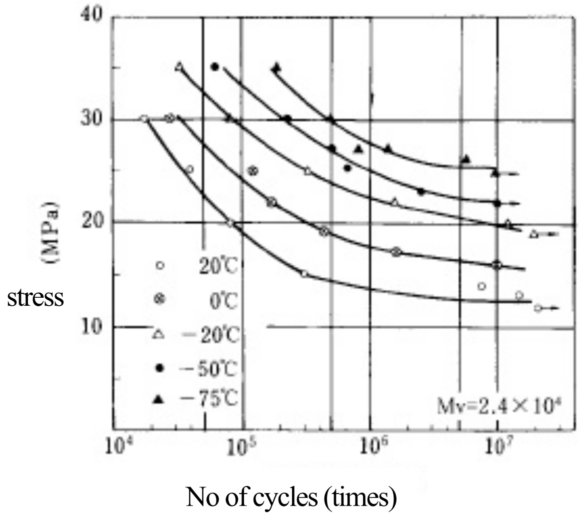


Fig. 3・8・1−5　Influence of temperature in fatigue resistance (flexure)

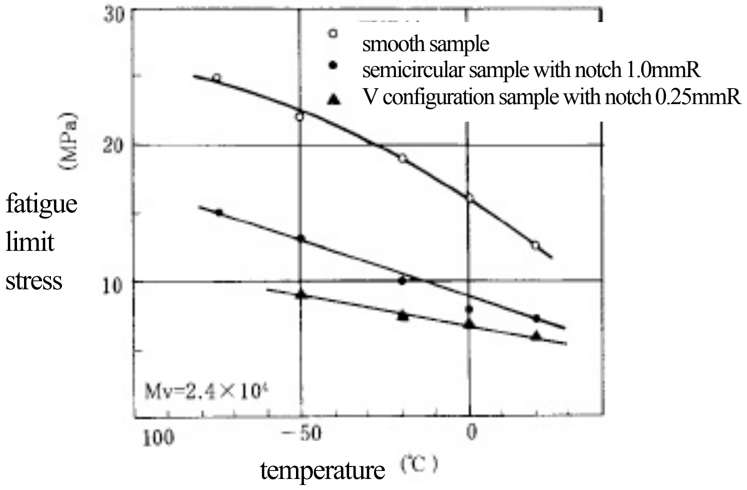


Fig.　3・8・1−6　Fatigue properties of samples with notch

The results of comparing the fatigue resistance by the Sonntag tester for various resins are shown in Table 3・8・1−1.

Table 3・8・1−1　Fatigue resistance of various resins

Name	Break stress MPa（kgf／cm2）			
	10^4 cycles	10^5 cycles	10^6 cycles	10^7 cycles
Vinyl chloride（PVC）	36. 3（370）	25. 5（260）	18. 7（191）	16. 7（170）
Polystyrene	24. 1（246）	14. 7（150）	10. 8（110）	10. 0（102）
Derivatives of fibrillar system	20. 8（212）	16. 2（165）	13. 2（135）	11. 1（113）
Polyamide（nylon）	15. 1（154）	12. 4（126）	12. 1（123）	11. 8（120）
Polyethylene	13. 7（140）	11. 8（120）	11. 3（115）	11. 0（112）
Polypropylene	16. 7（170）	13. 1（134）	12. 0（122）	11. 0（112）
Acrylate（PMMA）	30. 3（309）	27. 8（283）	27. 8（283）	27. 8（283）
Polycarbonate	40. 1（409）	26. 9（274）	14. 9（152）	9. 8（100）
Polyacetal		32. 3（329）	28. 3（289）	26. 9（274）
Polyphenylene ether (PPE)				8. 2−13. 7（84−140）
Polysulphone				6. 9（70）
Modified PPE				17. 2（175）

3・8・2 Creep Characteristics

The tensile creep characteristics, flexural, compression creep characteristics of Iupilon / NOVAREX are shown in Fig. 3・8・2−1, 2, 3 and 3・8・2−4, respectively. Also, a comparison with other resins is shown in Fig. 3・8・2−5 and 6.

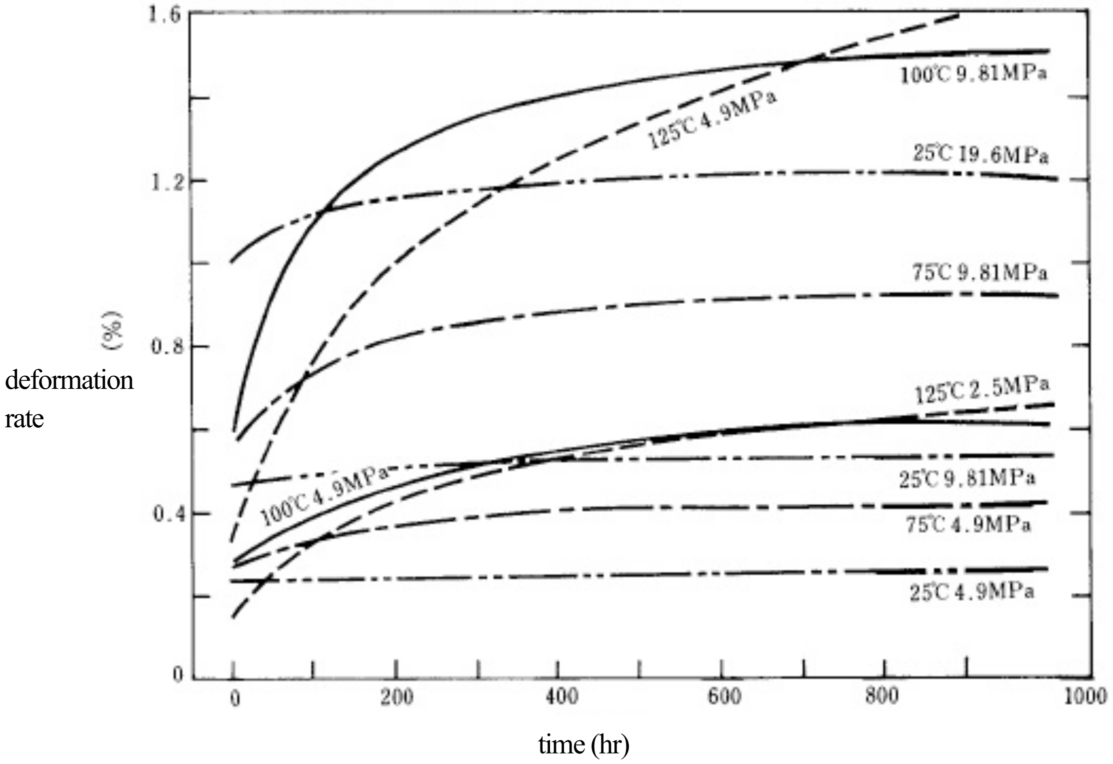
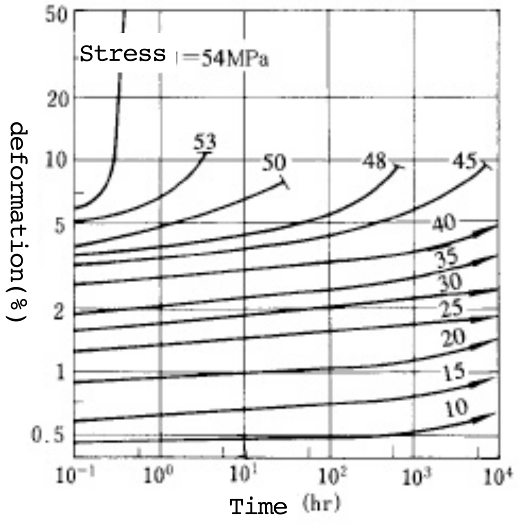


Fig. 3・8・2−1 Tensile creep of Iupilon / NOVAREX



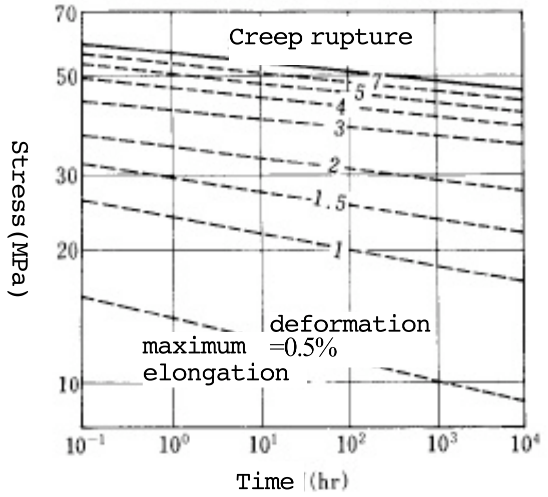


Fig. 3・8・2−2 Tensile creep of polycarbonate

Fig. 3・8・2−3 Tensile creep of polycarbonate (22℃)

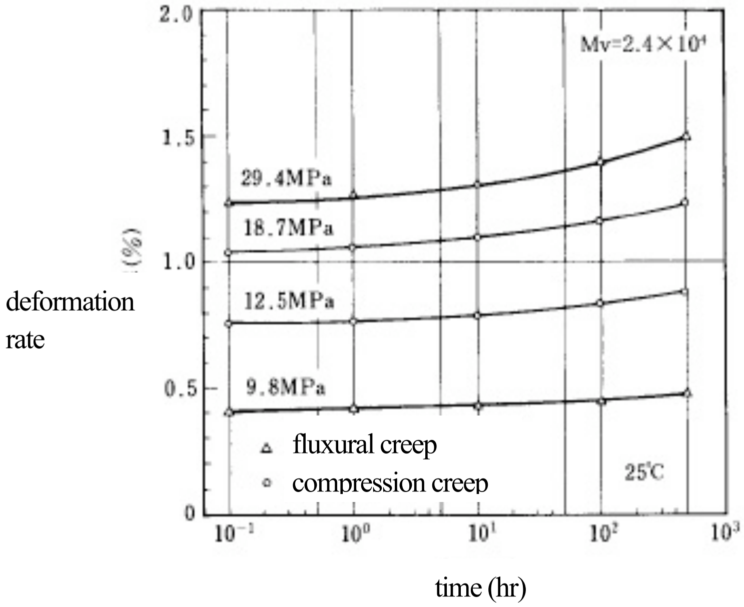


Fig. 3・8・2－4 Flexural, compression creep of Iupilon / NOVAREX

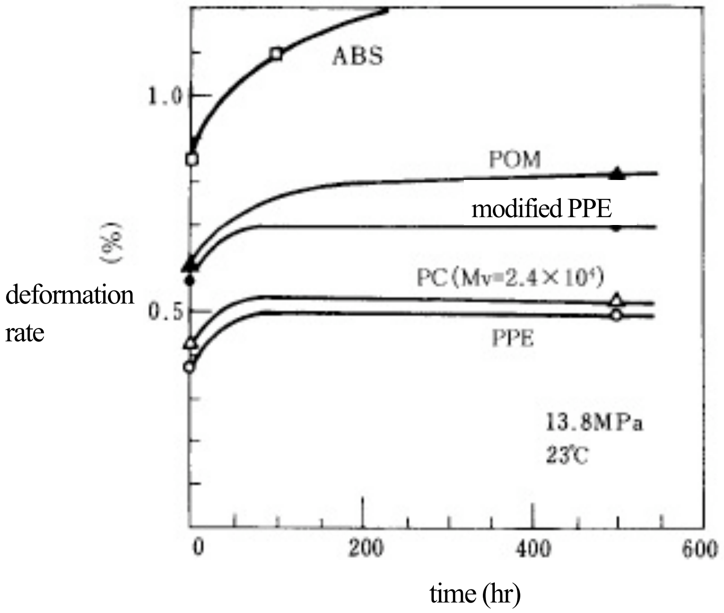


Fig. 3・8・2－5 Creep curve of other resins

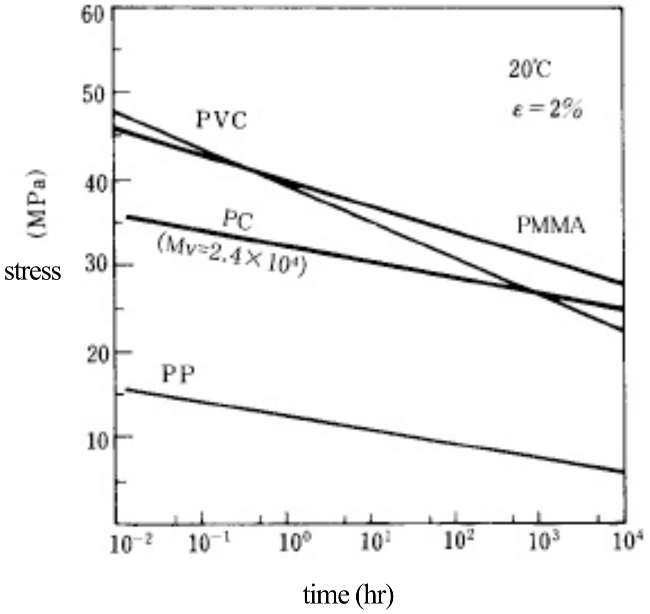


Fig. 3・8・2－6 Change by the time of stress that becomes 2 % of deformation rate

The creep rupture line of Iupilon / NOVAREX is shown in Fig. 3・8・2－7 and 8. A comparison with other resins is shown in Fig. 3・8・2－9.

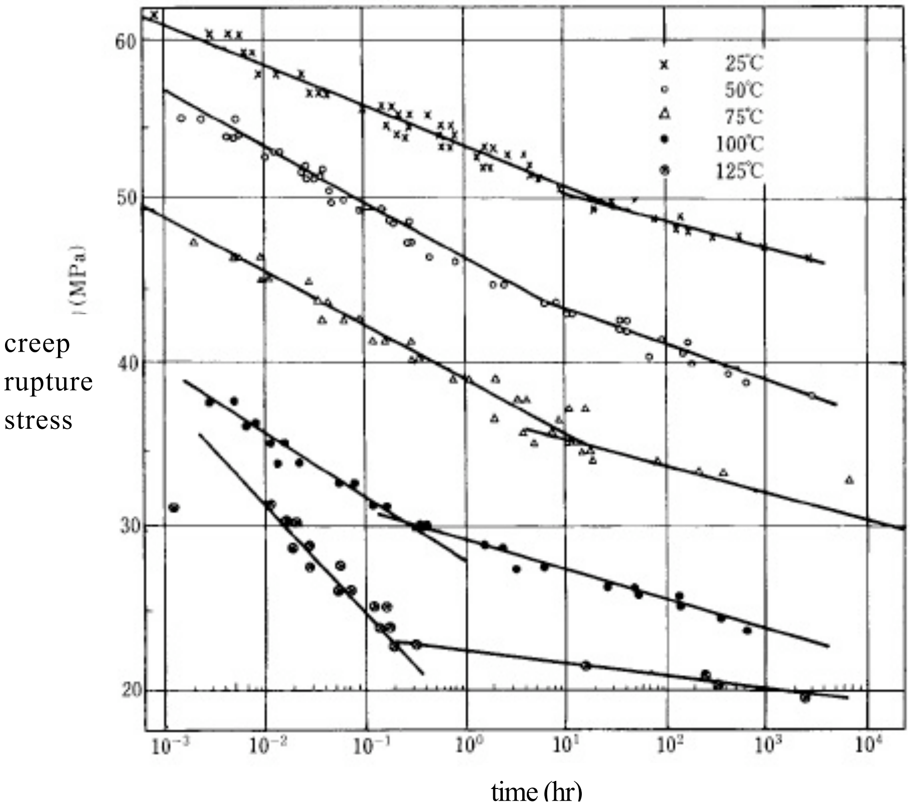
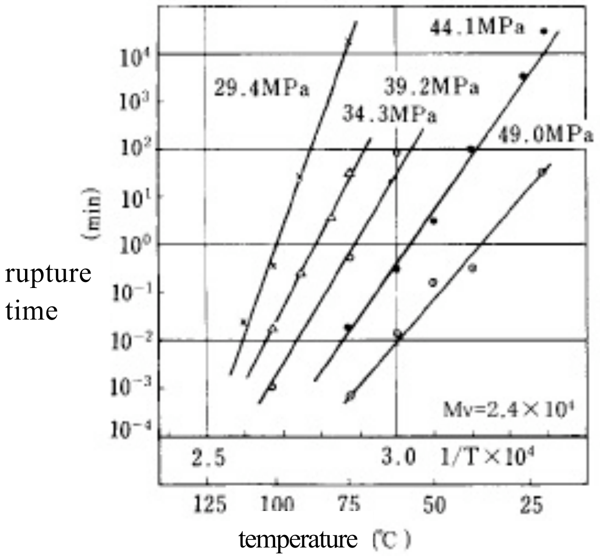


Fig. 3・8・2－7　Relation between temperature and creep rupture time（Mv=2.4 x 104）



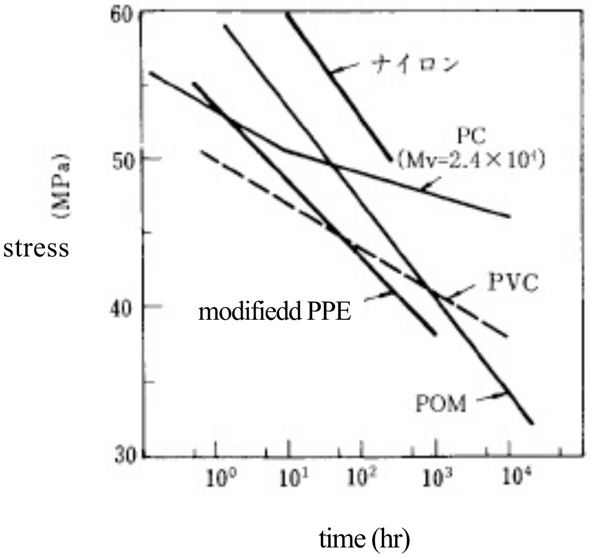


Fig. 3・8・2－8 Relation between temperature and creep rupture time

Fig. 3・8・2－9 Creep rupture curves of other resins

3・8・3 Deformation Under Load and Recovery

The deformation under compressive load of polycarbonate is as shown in Table 3・8・3－1.

Table 3・8・3－1

Temperature (℃)	Load MPa（kgf／cm^2）	ASTM－D621－51 Deformation after 24 hr. (%)
25	27. 5（280）	0. 220
70	27. 5（280）	0. 282
25	13. 7（140）	0. 101
70	13. 7（140）	0. 080

Also, when a compressive load of 1.11kN (113.4kgf) on ball (φ10.16) is applied, the rate of instantaneous recovery with a deformation of 1.42mm was 97% and the recovery rate was 100% after 5 days.

The tensile deformation and recovery of polycarbonate at 100℃ are shown in Table 3・8・3－2 (see Fig. 3・8・2－1).

The tensile deformation at normal temperature and recovery in case load was removed after 1,000 hours are shown in Fig. 3・8・3－1.

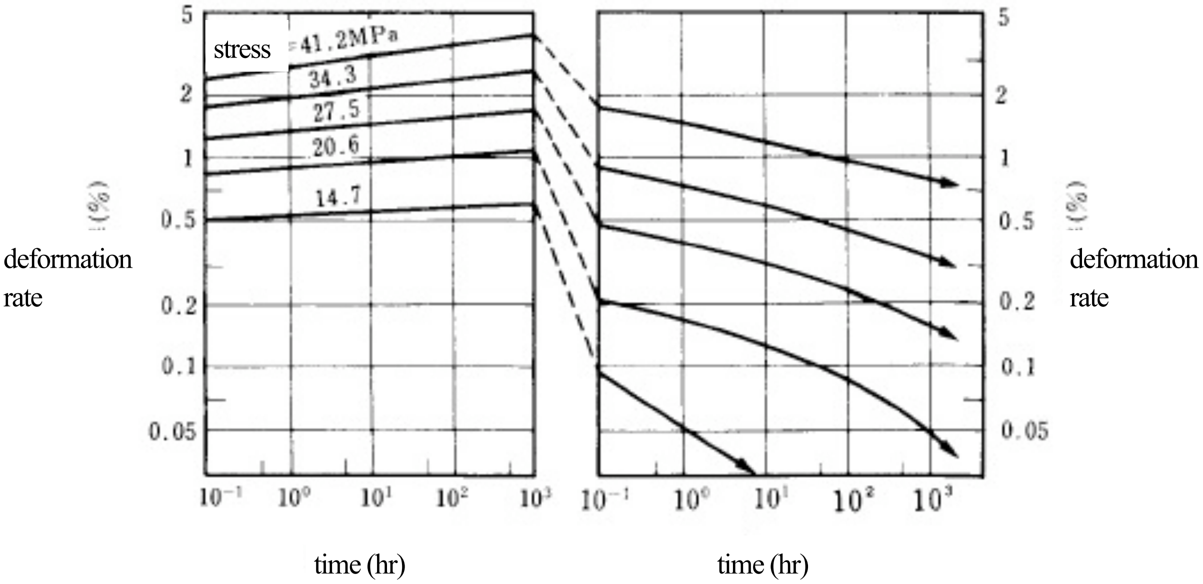


Fig. 3・8・3－1 Recovery behaviour of polycarbonate

Table 3・8・3－2

Stress MPa（kgf／cm^2）	Initial sttrain (%)	Creep after 1,000 hrs (%)	Total deformation (%)	Recovery rate (Recovery /Total deformation) (%)
3. 84（39. 2）	0. 0298	0. 2797	0. 3095	38. 5
7. 70（78. 5）	0. 3059	0. 6941	1. 000	32. 2
15. 4（157）	0. 7267	1. 300	2. 027	35. 3
19. 2（196）	1. 162	3. 500	4. 662	21. 0

3・8・4　Relaxation of Stress

The relaxation curves of tensile stress of Iupilon / NOVAREX are shown in Fig. 3・8・4ー1.

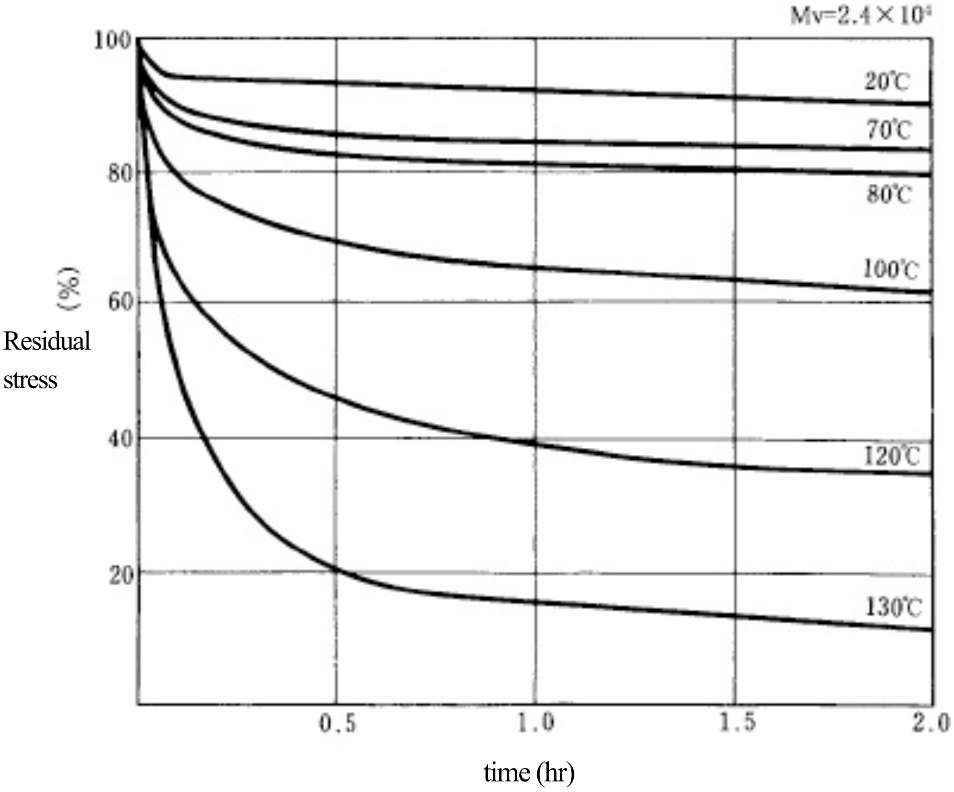


Fig. 3・8・4ー1　Relaxation of tensile stress of Iupilon / NOVAREX
(Initial load 9.8MPa, however, 4.9MPa in case of temperature of 120℃ and 130℃)

3・8・5　Practical Permissible Stress

Table 3・8・5ー1

	Practical Permissible StressMPa（kgf／cm^2）	
	Tensile	Compressive
Intermittent load（room temperature）	27. 5（280）	41. 2（420）
Intermittent load（in 52℃ air）	23. 5（240）	23. 5（240）
Intermittent load（in 100℃ air）	20. 6（210）	20. 6（210）
Intermittent load（room temperature, in moisture, vapor）	27. 5（280）	41. 2（420）
Permanent load（room temperature）	13. 7（140）	13. 7（140）
Repeating or oscillating	6. 9（70）	6. 9（70）

3・9　Stress Crack

When plastic is used for practical items, it sometimes encounters the phenomenon in which craze and crack are generated. There are two cases, that is, the generation of this craze and crack when only stress was added (stress crack), and by a microstress under the coexistence with foreign substance (environmental stress crack). Also, the craze and crack are clearly distinguished by the transmission electron microscope observation etc. That is, as for the craze, the density of the molecular chain is low by the local orientation and it becomes the structure that contains void like the sponge while the crack forms a complete space. However, because the craze and crack can not be strictly distinguished by the naked eye, the crack is also included in the craze of this report which was observed by the naked eye.

When adding a flexural load or flexure to the flexural test piece of Iupilon / NOVAREX, the craze is generated after a certain induction period (it can be considered that craze is generated in case of uniaxial stress). After that, the growth and termination of the generated craze or the generation of new craze etc. is observed. The knowledge about the induction period of craze generation becomes a very important issue from the practical view.

The relation between the induction period of craze generation and the flexural stress under constant load of Iupilon / NOVAREX was shown in Fig. 3・9-1. The induction period shifts to the extended period of time with the decrease of stress and becomes infinite finally. However, in case of Iupilon / NOVAREX, approximately 29.4MPa (300kgf/cm^2) at Mv＝2.4~3.0×10^4, approximately 19.6MPa (200kgf/cm^2) at Mv＝2.2×10^4 become the stress that the craze is not generated.

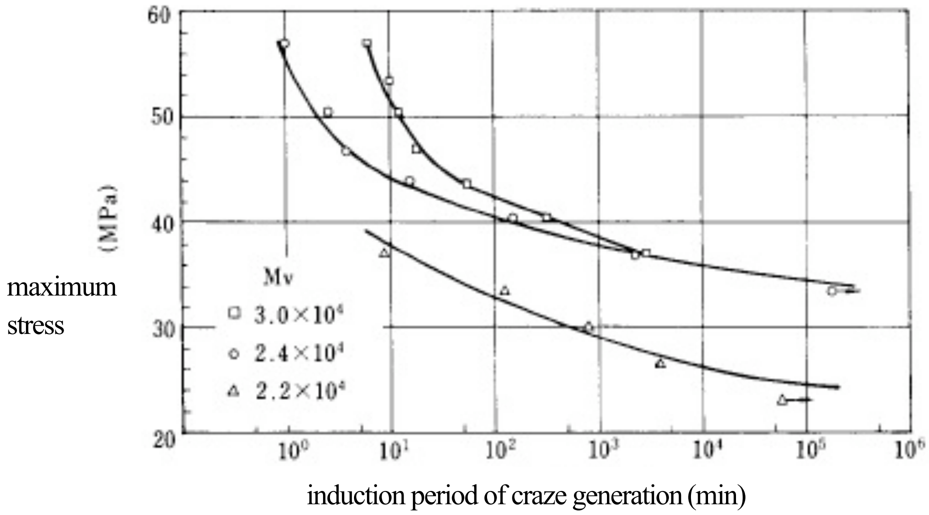


Fig. 3・9－1 Change in induction period of craze generation by flexural stress

The influence of heat treatment or additives on the craze generation is shown in Fig. 3・9－2. The craze generation by heat treatment becomes easy as indicated in this figure. The behaviour of the craze generation near the room temperature was shown in Fig. 3・9－3. As indicated in this figure, the rate of the craze generation rapidly becomes low at low temperature zone.

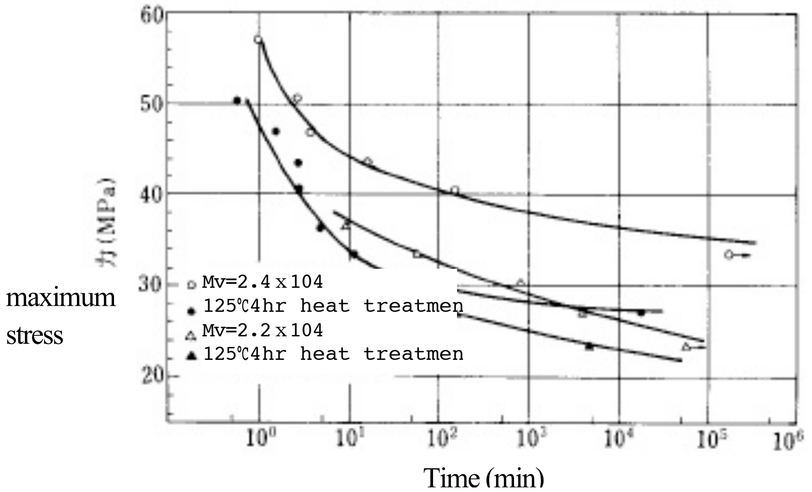


Fig. 3・9−2 Change in induction period of induction period of craze generation (min) on temperature: room temperature)

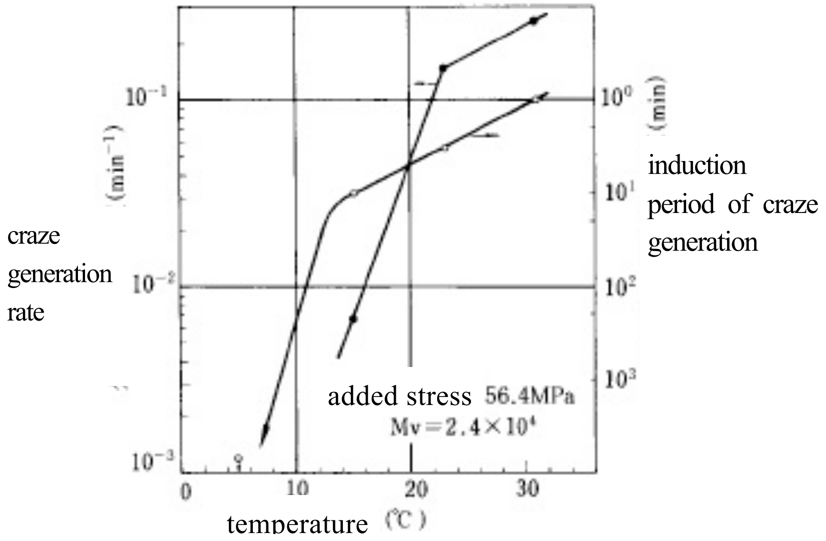


Fig. 3・9−3 Behaviour of craze generation in the vicinity of room temperature

The behaviour of craze generation in case of adding the constant strain to flexural test piece of Iupilon/ NOVAREX was shown in Fig. 3・9−4, 5, 6, 7 and 8. The influence of temperature was shown in Fig. 3・9−4, 5, the craze generation becomes easy with the increase of atmosphere temperature.
The influence of the molecular weight was shown in Fig. 3・9−6. The influence of heat treatment was shown in Fig. 3・9−7 and 8. The craze generation becomes easy as the case of the constant load.

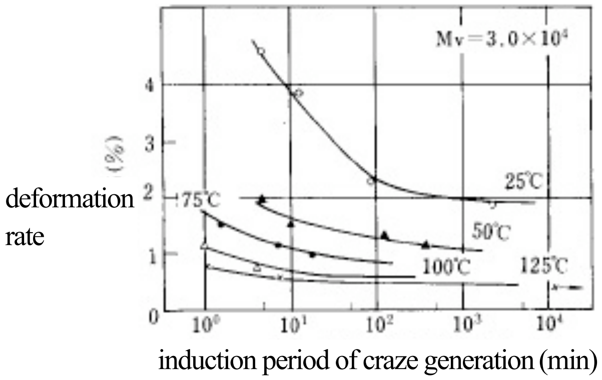


Fig. 3・9−4 Induction period of craze generation under constant strain

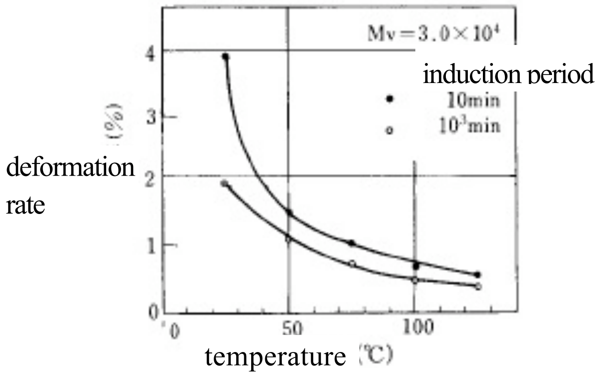


Fig. 3・9−5 Influence of temperature on induction period of craze generation

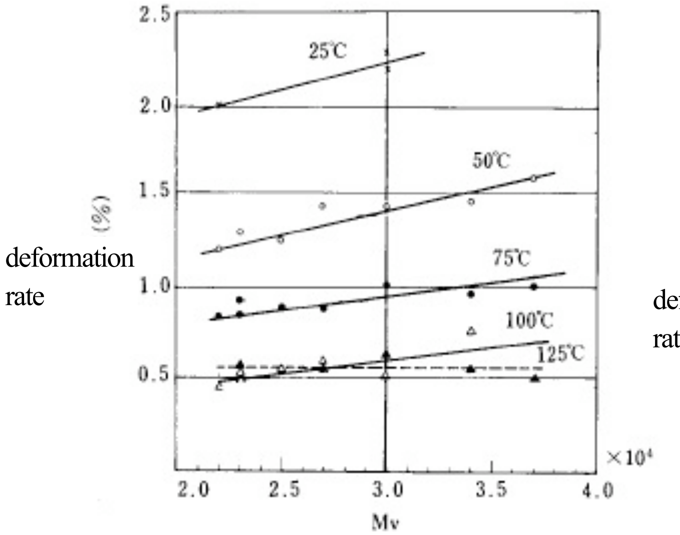


Fig. 3・9―6 Influence of molecular weight on induction period of craze generation (when the induction period becomes100min.)

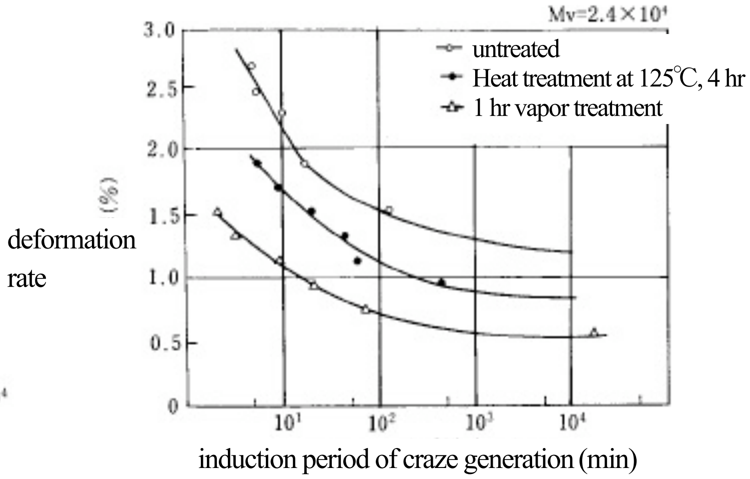
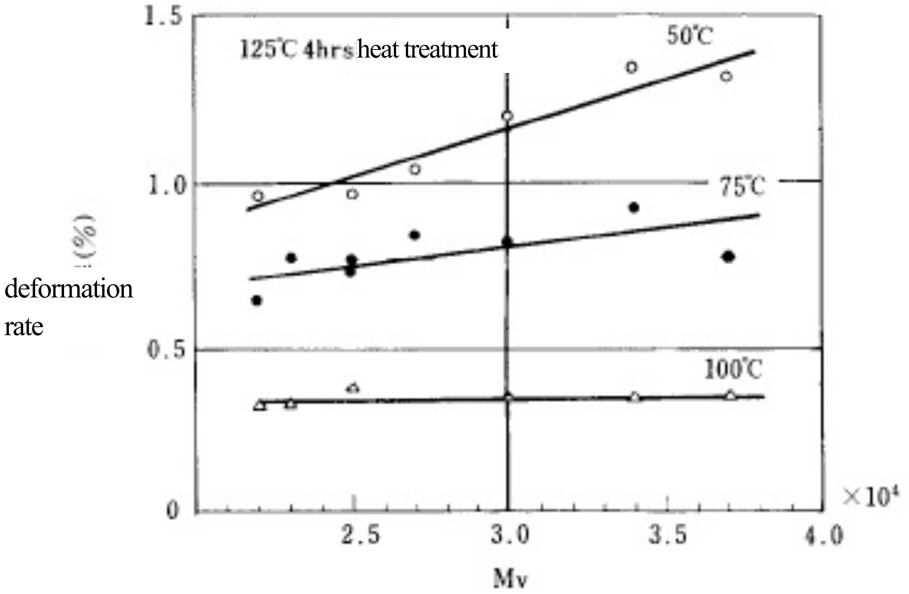


Fig. 3・9―7 Change in induction period of craze generation by heat treatment (determinationtemperature:50℃)



Fig, 3・9―8 Influence of molecular weight on induction period (100min) of craze generation of heat-treated sample

4. Thermal Properties

4・1 Transition Point

4・1・1 Glass Transition Point (Secondary Transition Point)

The glass transition point of polycarbonate obtained from the inflection point of refractive index is 141~149℃, as shown in Fig. 4・1・1−1. In addition, the glass transition point obtained by the measurement of expansion coefficient, specific heat, differential thermal analysis, and viscoelasticity, etc. is in the range of 130~155℃.

When the glass transition point is studied in further detail, it differs in accordance with the molecular weight, as shown in Fig. 4・1・1−2 (Tg was obtained by the differential thermal analysis).
Also, the glass transition point is known to have the pressure dependence and as for polycarbonate, it is as follows:

$$\delta T_g / \partial p = 0.044\text{℃/atm}$$

A comparison with other resins is shown in Table 4・1・1−1.

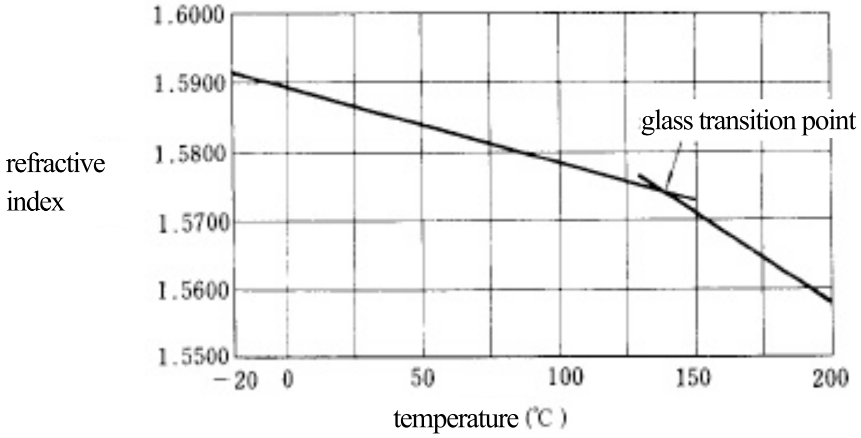


Fig. 4・1・1−1 Temperature characteristics of refractive index of polycarbonate

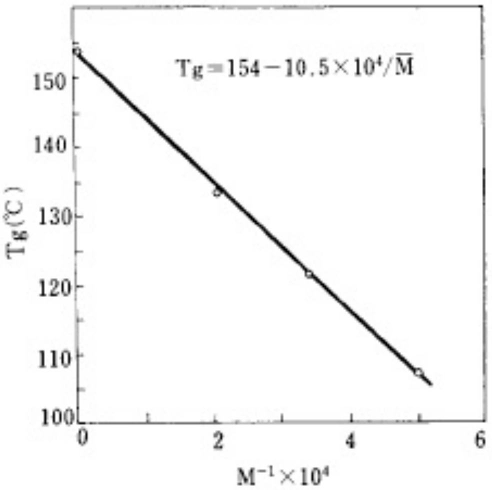


Fig. 4・1・1−2 Relation between Tg (glass transition point) and M (molecular weight)

Table 4・1・1—1　T_m, T_g and dispersion temperature of other resins

Name	T_m melting point	T_g glass transition point (℃)	Dispersion temperature				
			Crystalline dispersion	Primary dispersion	Secondary dispersion	Secondary dispersion	Secondary dispersion
Polyethylene	107—138	—53——23	60 72	—18 — 8 23	—126 —111 — 65		
Polypropylene	168—170	—35	82	— 2 22	— 83 — 40	—215 —173	
Polyvinyl chloride (PVC)	217	77		91 117 127	— 38 12		
Polyvinylidene chloride	190	—18	77	33	— 23		
Polytetrafluoroethylene	327	—73——63	127 150	—33	— 93 — 66 — 31		
Polystyrol	230	80—90		117 131 148	40	—153 — 53 87	
Polymethyl methacrylate (PMMA)		82—102		127 143 167	27 103	—115 — 69 17	—183 —143 — 53
Polyvinyl acetate		7—27		30 90	— 47	—113 —17	
Polyethylene・terephthalate (PETP)	265	63—83		57 127	—10 7		
Polyoxymethylene	177	—40——60	127	—13 45 127	— 73 — 58 — 33		
Nylon 6	223	33—53		57 82	— 61 — 23 32	—128 —105 30	
Nylon 66	275	33—53		67 82	— 53 — 23	—125 —103	

Note: The upper, middle and lower dispersion temperatures are the measuring results at 1, 10^3 and 10^6Hz., respectively.

4・1・2 Melting Point

The melting point of Iupilon / NoVAREX pellet is 220～230℃.

The melting point of crystallized polycarbonate is about 230～260℃ (Refer to Fig. 4・5・2－2).

The melting heat of the crystalline is 134J/g (32cal/g).

The melting point of other resins is shown in Table 4・1・1－1.

4・1・3 Dispersion temperature

As for the thermoplastic resin, it is known that there are the primary dispersion zone where the macro-Brownian motion of molecular chain occurs, and the secondary dispersion zone where the local thermal motion (for example, thermal motion of methyl group of a part of main chain or side chain) occurs. Polycarbonate is not exception, too and its exixtence is recognized in many literatures.

The dispersion temperature of polycarbonate is summarized in Table 4・1・3－1.

Table 4・1・3－1 Dispersion temperature of polycarbonate

Dispersion type	Primary dispersion α	Secondary dispersion β	Secondary dispersion γ	Secondary dispersion δ
Dispersion temperature (℃)	157 (1) 175 (10^3) 195 (10^5)	0—100	—100 (1) —80 (10^3) —3 (10^6)	—200 ～ —100
Thermal motion type	Macro-Brownian motion of main chain		Free rotation motion of the C=0 group which accompanies the restricted motion of the phenyl group	Free rotation motion of the Me group (by MMR)

The results of these dispersions are shown in Fig. 4・1・3－1, 2, 3 and 4. The primary dispersion, theγ dispersion and the δ dispersion are shown in Fig. 4・1・3－1, 4・1・3－2, 4・1・3－3, respectively. As for theβ dispersion, its existence is recognized in many literatures but there is not definite one. Fig. 4・1・3－4 is an example. Refer to Table 4・1・1－1 for other resins.

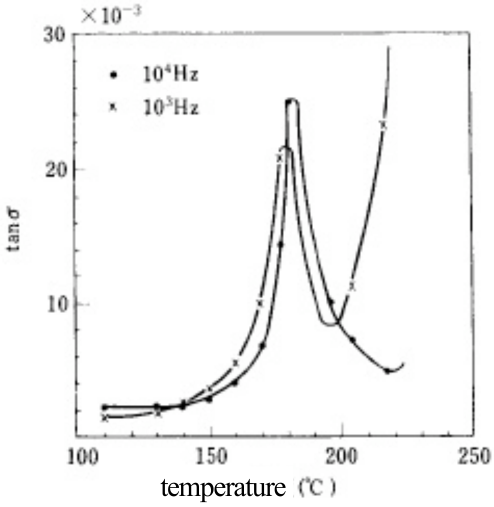


Fig. 4・1・3－1 Change in tan δ at primary dispersion zone

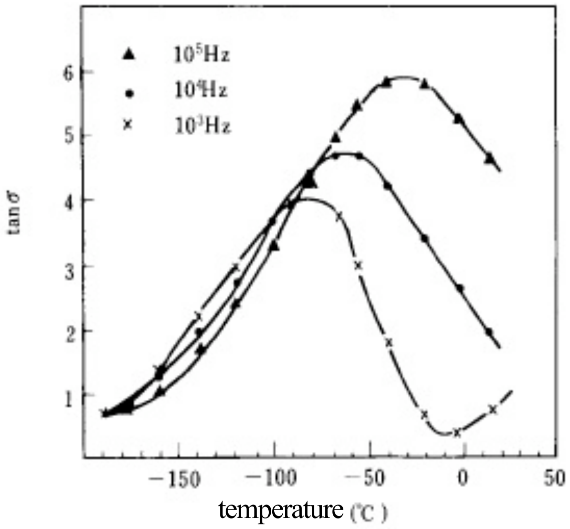


Fig. 4・1・3－2 Change in tan δ at low temperature zone

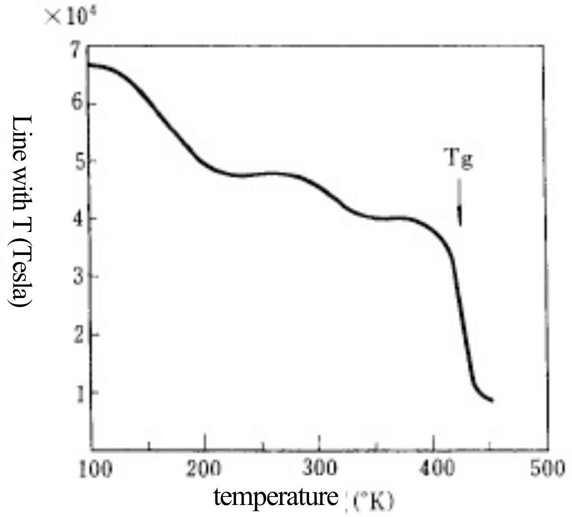


Fig. 4・1・3−3 NMR of polycarbonate Change in temperature of Line width（1Gs＝10^{-4}T）

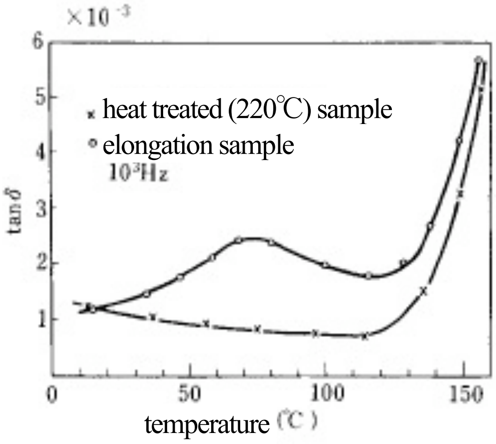


Fig. 4・1・3−4 Change in tan δ at low temperature zone

4・2 Thermal Conductivity and Specific Heat

As shown in Fig. 4・2−1, the specific heat of polycarbonate changes with temperature but it can be considered that this is 1.09～1.17J/(g.k) (0.26～0.28cal/g.℃）for the practical temperature range. This value does not differ very much from the common synthetic resins and corresponds to about 3 times of iron and copper etc.

The thermal conductivity of polycarbonate is

0.19W/(m.k)(4.6x10^{-4}cal/cm.sec℃）

This value does not differ very much from the common synthetic resins and is very small when compared with those of metals as it is 1/400 of iron, 1/1000 of aluminum and 1/2000 of copper.

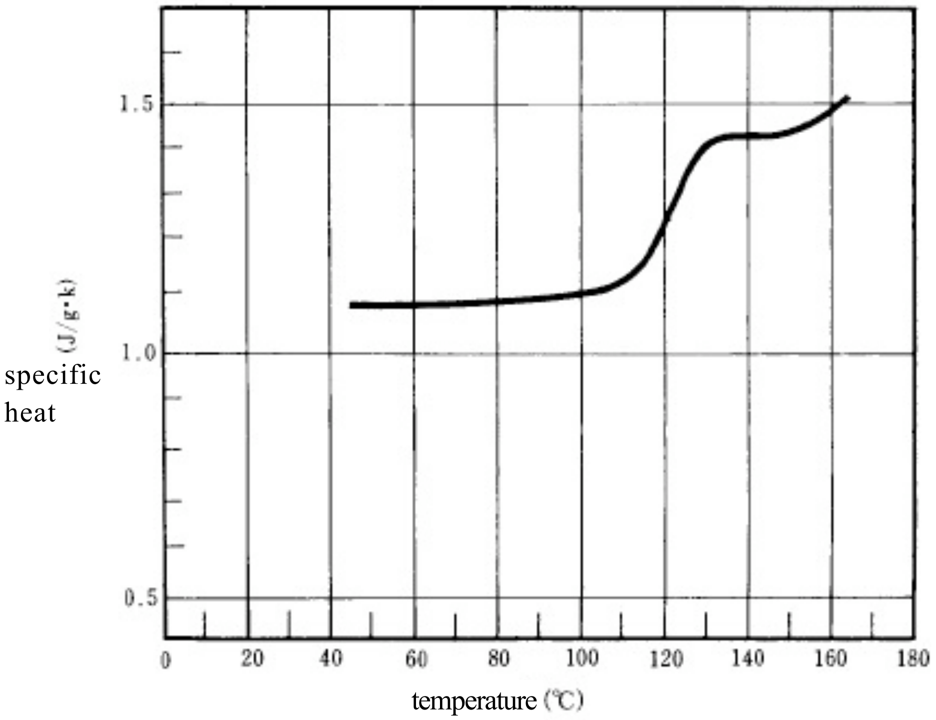


Fig. 4・2−1 Specific heat – temperature characteristic of polycarbonate

The thermal conductivity and specific heat of other resins are shown in Table 4・2－1

Table 4・2－1　Comparison of thermal properties

Name	Thermal conductivity W／（m・k）(cal/cm. sec℃) X 10^{-4}	Specific heat kJ／（kg・k）(cal／g・℃)	Linear expansion coefficient 10^{-5}・k^{-1}	Brittle temperature ℃	Deflection temperature under load（℃）	
					1820kpa (18. 6kgf／cm^2)	455kpa (4. 6kgf／cm^2)
Low density polyethylene	0. 33 (8)	2. 3 (0. 55)	16－18	－85－－55	32－41	38－49
High density polyethylene	0. 46－0. 52 (11－12. 4)	2. 3 (0. 55)	11－13	－140	43－54	60－88
Polypropylene	0. 14 (3. 3)	1. 9 (0. 46)	6－10	－10－－35	57－63	93－110
Acrylate（PMMA）	0. 17－0. 25 (4－6)	1. 5 (0. 35)	5－9	90	70－100	74－110
Polystyrene	0. 10－0. 14 (2. 4－3. 3)	1. 4 (0. 33)	6－8		80－90	
Polyvinyl chloride	0. 13－0. 17 (3－4)	1. 0 (0. 24)	5－6	81	54－79	57－82
Polyvinylidene chloride	0. 13 (3)	1. 3 (0. 32)	19	0－－30	55－65	
Polytetrafluoroethylene	0. 25 (6)	1. 0 (0. 25)	10			121
Polyvinyl acetate	0. 16 (3. 8)	1. 6 (0. 39)	8. 6		38	
Acryl nitrile・Styrene（AS）	0. 12 (2. 9)	1. 4 (0. 33)	6		88－102	
66 Nylon	0. 22－0. 24 (5. 2－5. 8)	1. 7 (0. 40)	10－15		66	
6 Nylon	0. 21 (5. 0)	1. 6 (0. 38)	8－13	－85－60	62	150
Polyethylene・terephthalate（PETP）			27			
Polyether	0. 23 (5. 5)	1. 5 (0. 35)	8. 2	－76－－120	110	170
Triacetyl cellulose	0. 17－0. 33 (4－8)	1. 5 (0. 35)	8－16		44－91	49－98
Modified PPE	0. 22 (5. 2)	1. 3 (0. 32)	5. 6	＜－40	117	128
Polysulfone		1. 3 (0. 3)	5. 6		174	181
Polycarbonate	0. 19 (4. 6)	1. 1 (0. 27)	6	－135	130－136	136－142

4・3 Coefficient of Thermal Expansion

The coefficient of linear expansion of Iupilon / NOVAREX at 20~120℃ is

$6\sim7 \times 10^{-5}$/K

The coefficient of volume expansion of Iupilon / NOVAREX at 30~130℃ is

$(20\pm5) \times 10^{-5}$/K

The change in length and volume weight ratio is shown in Fig. 4・3－1 and 2, respectively. The relation between temperature and volume expansion coefficient is shown in Fig. 4・3－3. The coefficient of linear expansion has the refraction point near the room temperature and becomes small in the low temperature region.

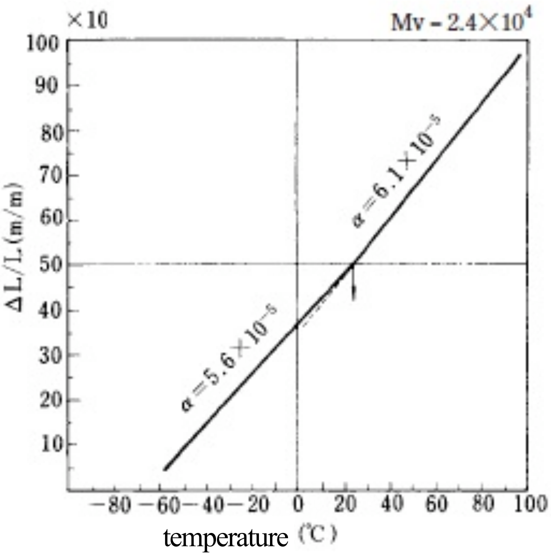


Fig. 4・3－1 Coefficient of linear expansion of Iupilon / NOVAREX

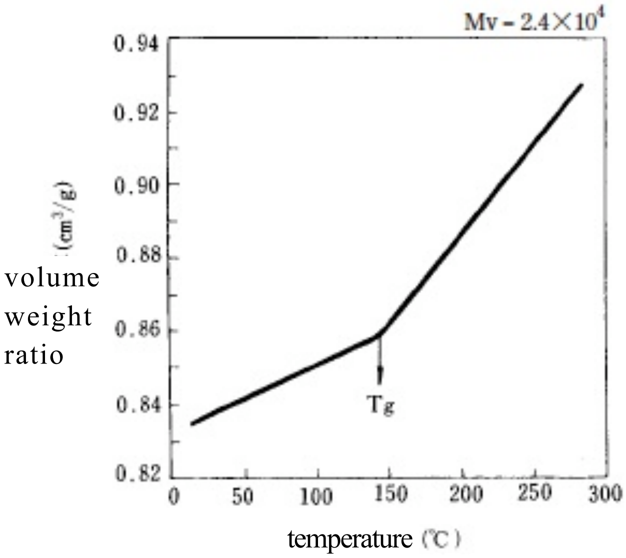


Fig. 4・3－2 Relation between temperature and volume weight ratio

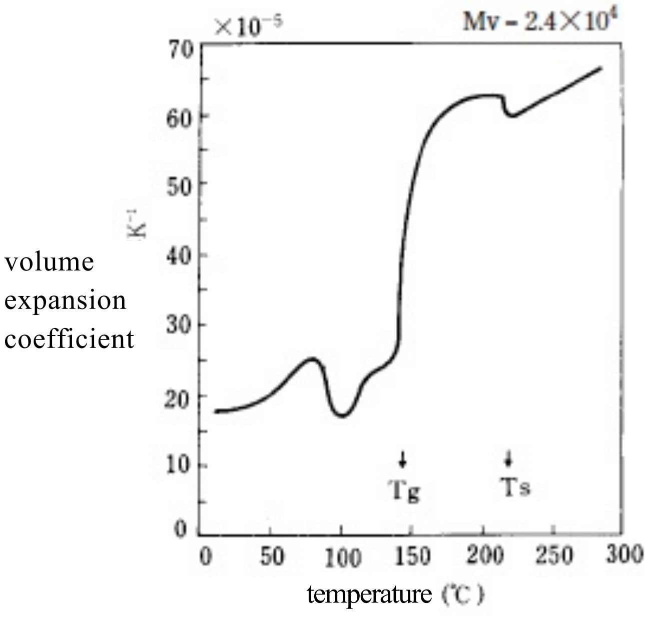


Fig. 4・3－3 Relation between temperature and volume expansion coefficient

4 . 4 Deflection Temperature

The deflection temperature（ASTM－D648－56）of Iupilon / NOVAREX is

Stress 1.82MPa (18.6kgf/cm^2)　　132～138℃
Stress 0.45MPa (4.6kgf/cm^2)　　138～144℃

The deflection temperature changes in accordance with the added load and is shown in Fig. 4・4－1 in case of Iupilon / NOVAREX. Also, the deflection temperature is influenced by the molecular weight in the same way as Tg (glass transition point) as shown in Fig. 4・4－2.

When Iupilon / NOVAREX is heat-treated, as indicated in other physical properties, the heat hardening is shown and the deflection temperature changes rapidly as shown in Fig. 4・4－3.

A comparison with other resins is shown in Table 4・2－1 and Fig. 4・4－4.

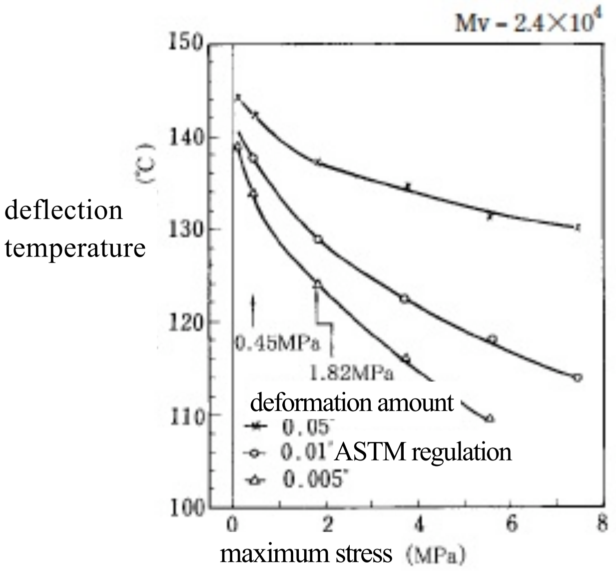


Fig. 4・4－1　Change in deflection temperature by load molecular

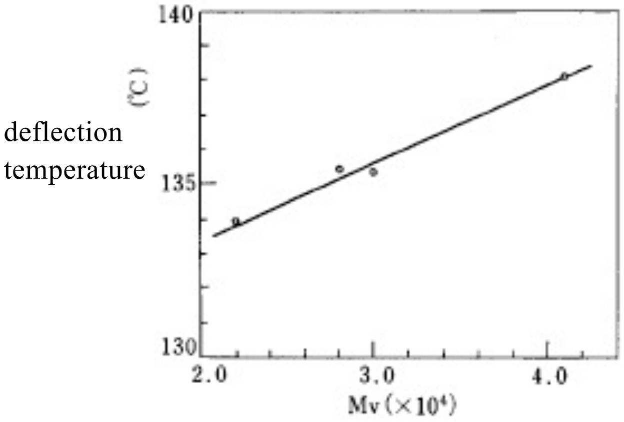


Fig. 4・4－2　Relation between weight and deflection temperature（Stress 1.82MPa）

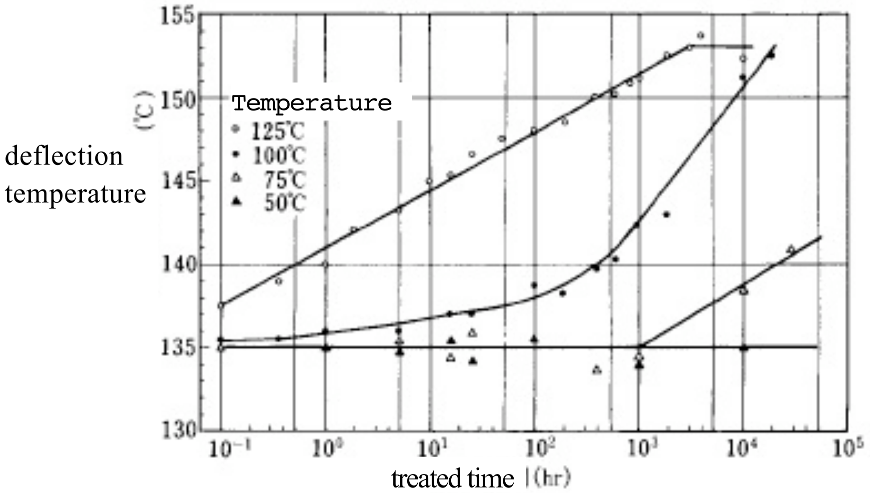


Fig. 4・4－3　Change in deflection temperature by heat-treatment (Stress 1.82MPa)
（Mv＝2. 8×10^4）

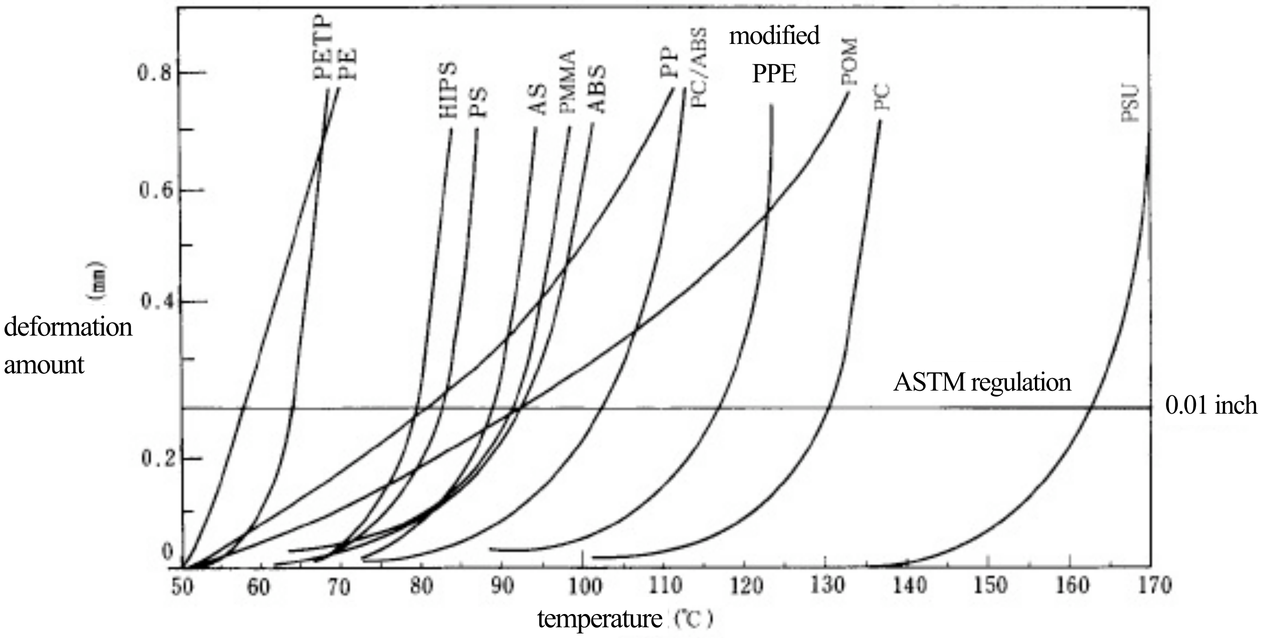


Fig. 4・4－4　Deflection temperature of other resins (Stress 1.82MPa)

4・5　Thermal Stability and Pyrolysis

It is possible to know the excellent heat resistance as shown in Fig. 4・5・2－2 where the differential thermal analysis result of Iupilon / NOVAREX is indicated. However, when examining it more in detail, the different aspect of every change in various temperature regions (practical temperature region, processing temperature region, decomposition combustion region), in the environment (in oxygen, in air, in nitrogen, in vacuum, in steam) is recognized.

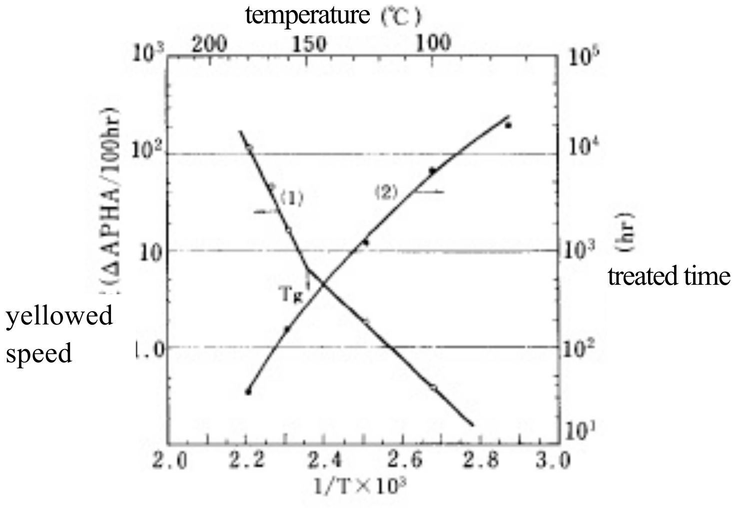
4・5・1 Low temperature region

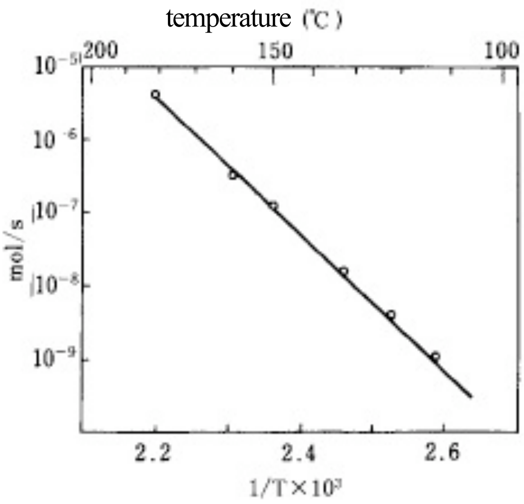
When Iupilon / NOVAREX is heat-treated at the temperature below Tg, the fact that the change in physical properties occurs due to the hardening phenomenon has already been known and there are a lot of researches to look for the cause in the change of the solid structure. However, when heating it in air at this temperature region for long time, it is observed that the chemical changes (oxidation, decomposition), discoloration, decrease in molecular weight etc. take place.

The result of arranging the yellowed degree of this temperature region is shown in Fig. 4・5・1－1. Curve (1) shows the influence of temperature on the yellowed speed, but the aspect of change is different at the up-and-down region of Tg. This might be due to the difference of the thermal effect of the molecular chain, that is, the difference of oxygen diffusion speed. Curve (2) shows the relation between temperature and treated time that the yellowed degree becomes equivalent.

Fig. 4･5･1-2 shows the CO_2 generation speed at this temperature region and the breakage of carbon bond, namely the decrease in molecular weight.

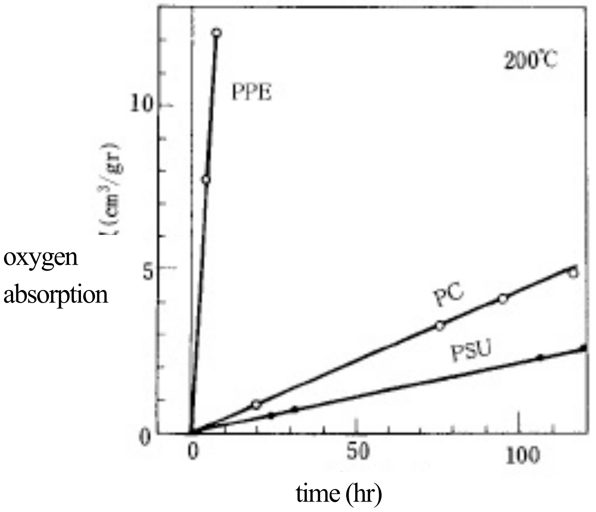
Fig. 4・5・1－3 and 4 show the comparison of the oxidation with other resins and the antioxidative property of polycarbonate.





Fig, 4・5・1−1 Yellowed speed of Iupilon / NOVAREX (Mv＝2.4×10^4)

Fig. 4・5・1−2 CO_2 generation at 110~180℃ (Mv＝2.4×10^4)



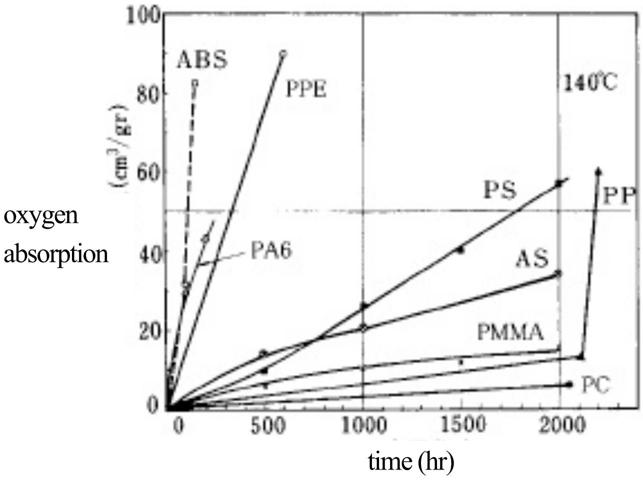
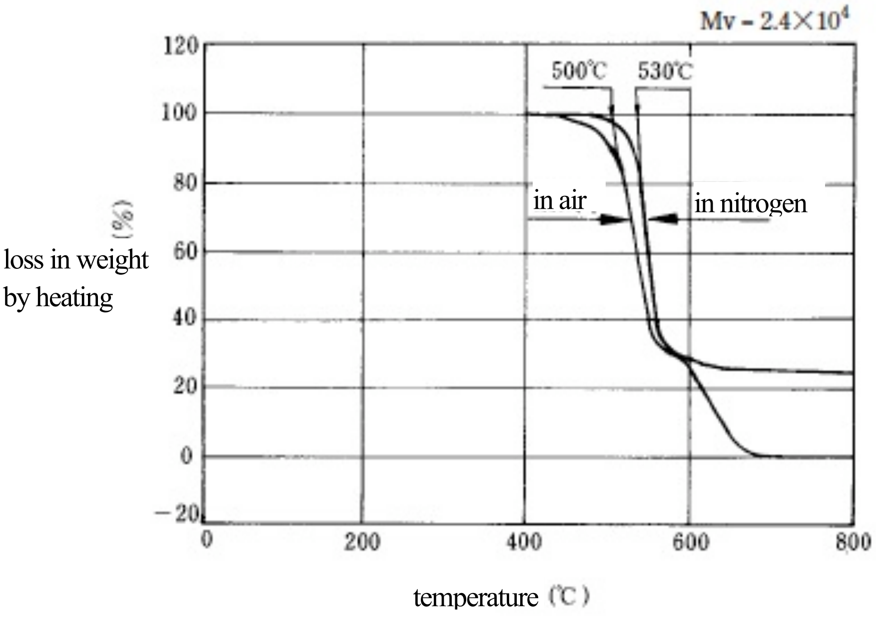


Fig. 4・5・1−3　Oxygen absorption speed at 200℃

Fig. 4・5・1−4　Oxygen absorption speed of various resins

4・5・2　High temperature region

The heat stability of Iupilon / NOVAREX is excellent. As shown in Fig. 4・5・2−1, the change in heat stability is observed at the temperature above 450℃, and the influence of atmosphere, impurities, and additives is large in such a high temperature region, especially oxygen and moisture promote the heat degradation considerably.



rate of temperature increase 20℃/ min
gas velocity 30cm3 / min
dried sample

Fig. 4・5・2−1　Thermobalance analysis result of Iupilon / NOVAREX

The pyrolysis of Iupilon / NOVAREX、consists of one exothermic region and two endothermic regions as shown from the result of the differential thermal analysis in Fig. 4・5・2−2. The exothermic region is the first stage of pyrolysis, the oxidation reaction is observed as an exothermic peak that starts at about 340℃and is highest at about 470℃. The first endothermic region is based on the depolymerization and peaks at 500℃. The second one is the region where the bond energy becomes equivalent to thermal energy, and dissociation of all molecular bonds takes place. The exothermic peak based on thermal oxidation and endothermic peak also decrease considerably in nitrogen and show that the influence of oxygen is remarkable.

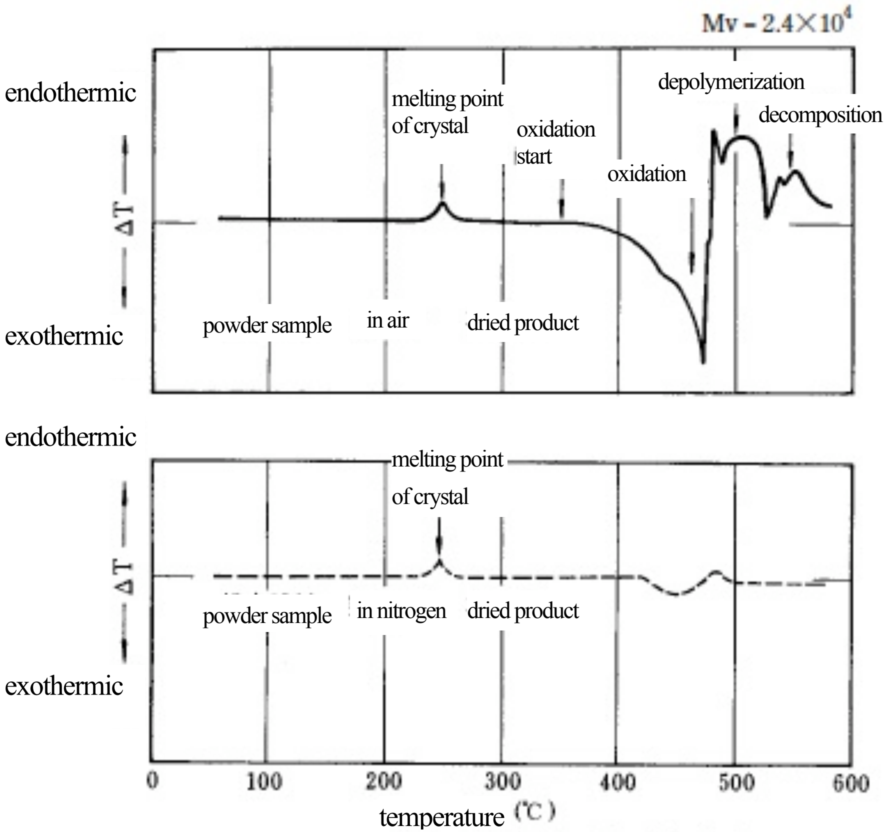
The decomposition gases generated by pyrolysis change by atmosphere as shown in Table 4・5・2−1, but CO, CO_2 by the decomposition of carbonic acid group, CH_4 by the dissociation of methyl group, and various phenols by the decomposition of BPA (bisphenol A) are main decomposition products. The generation of CO_2, CH_4, and various phenols are shown in Fig. 4・5・2−3, 4 and 5.

The generation becomes active at around 300℃ in air, but shifts to high temperature side about 50℃in nitrogen atmosphere.

The decrease in molecular weight of Iupilon when heated for 2 hours in nitrogen and in air is shown in Fig. 4・5・2−6 and 7.

Also, the result of heating for a long time in the sealed tube in vacuum was shown in Fig. 4・5・2−8.

The relation between temperature and pyrolysis kinetics is shown in Fig. 4・5・2−9, 10, and the influence of oxygen and moisture is extremely big.



Base substance: Molten quartz　Rate of temperature increase: 8℃/min.
Packing method: Sandwitch method

Fig. 4・5・2−2　Result of differential thermal analysis of Iupilon / NOVAREX

Table 4・5・2－1　Decomposition products of polycarbonate

（＋）：generated

Decomposition products	In oxygen	In air	In vacuum sealed	In vacuum continuous	Decomposition products	In oxygen	In air	In vacuum sealed	In vacuum continuous
CO_2	＋	＋	＋	＋	Benzene	＋	＋		
CO	＋	＋	＋	＋	Toluene	＋	＋		
CH_4	＋	＋	＋	＋	Ethyl benzene	＋	＋		
H_2	＋				Phenol	＋	＋	＋	＋
H_20	＋	＋	＋		Cresol	＋	＋	＋	＋
HCHO	＋				Ethyl phenol		＋	＋	＋
CH_3CHO	＋								
Acetone		＋							
Methanol	＋				Isopropyl phenol		＋	＋	＋
Diphenyl					Isopropenyl phenol		＋	＋	＋
			＋	＋	Bisphenol A	＋	＋	＋	＋

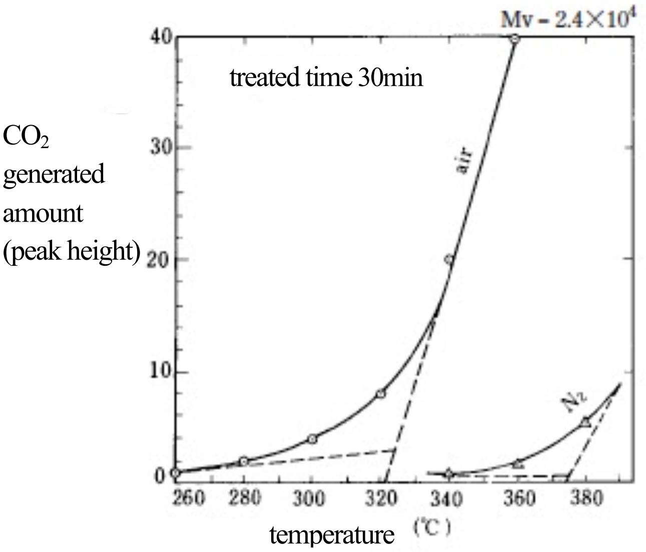


Fig. 4・5・2－3　Influence of atmosphere on CO_2 generated amount

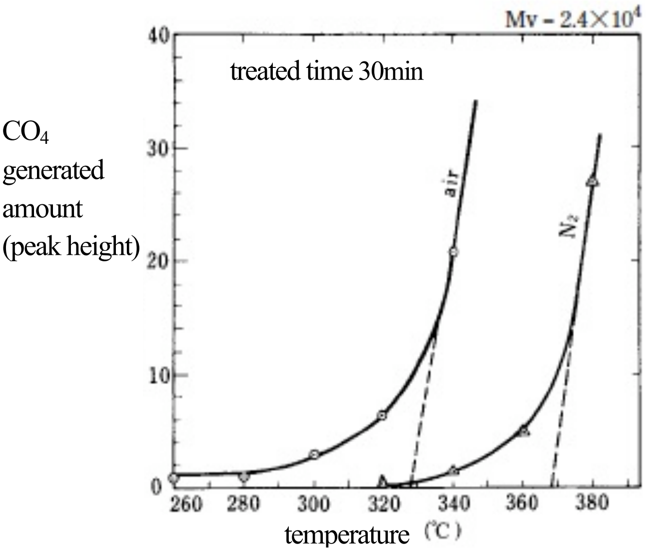


Fig. 4・5・2－4　Influence of atmosphere on CH_4 generated amount

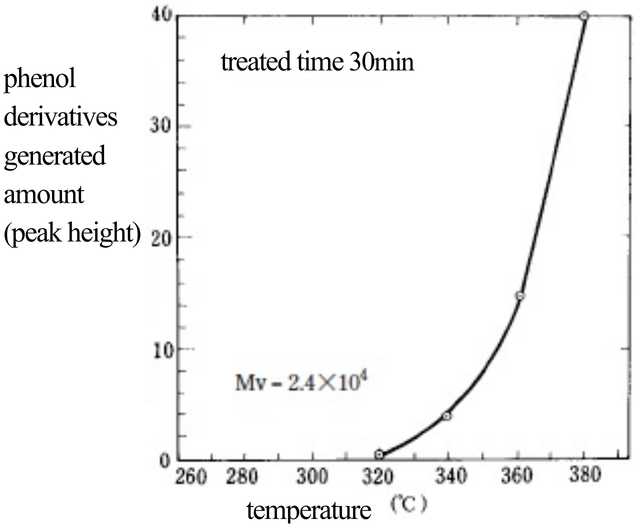


Fig. 4・5・2－5　Relation between temperature and generated amount of phenol derivatives by decomposition when heated in air

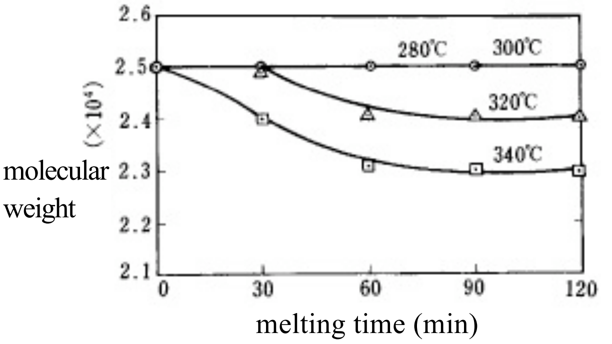


Fig. 4・5・2－6 Decrease in molecular weight of Iupilon / NOVAREX by meltin (Completely dry, melted in nitrogen stream)

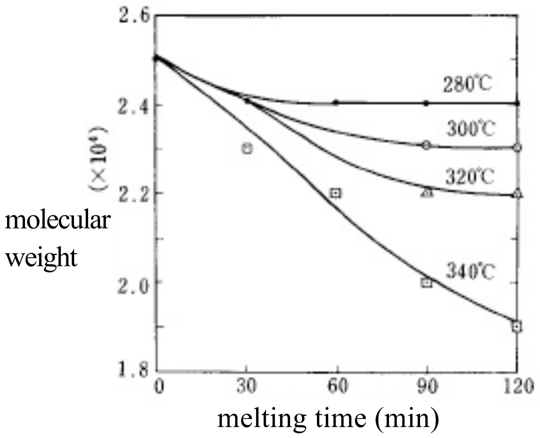


Fig. 4・5・2－7 Decrease in molecular weight of Iupilon / NOVAREX by melting (Undried, melted in air)

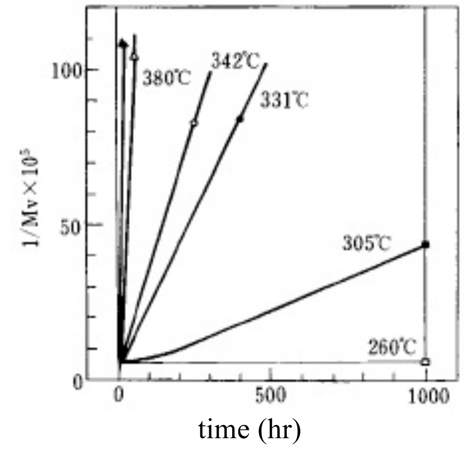


Fig. 4・5・2－8 Decrease in molecular weight (Mv) of sealed tube in vacuum

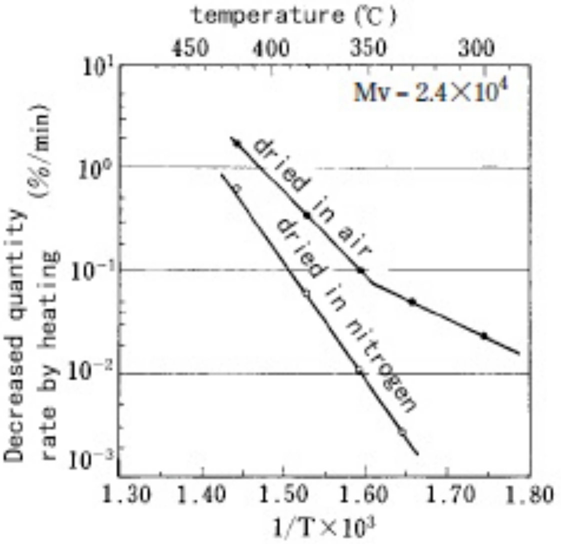


Fig. 4・5・2－9 Decreased quantity rate of Iupilon / NOVAREX by heating

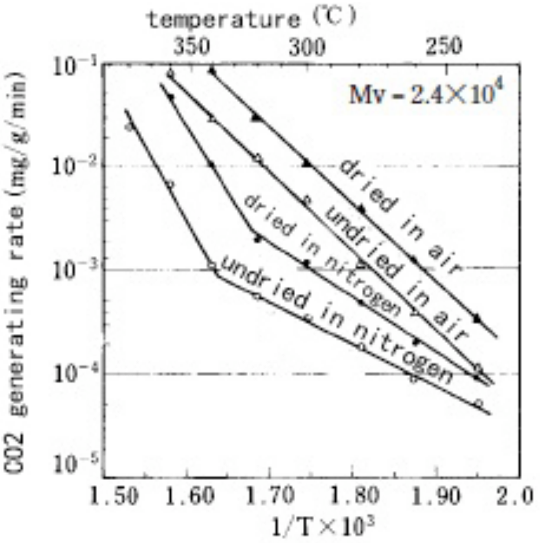


Fig. 4・5・2－10　CO_2 generating rate of Iupilon / NOVAREX

When the inorganic filling agent is added to Iupilon / NOVAREX, the influence on the pyrolysis is big. For ezample, decreased quantity rate in case of adding an iorganic filling agent in Fig.4・5・2－11 and CO_2 generated amount in Fig. 4・5・2－12 indicate the value which is bigger than the material in any case. Also, the influence of metal salts is shown in Table 4・5・2－2. The influence of carbonates is extremely big, and the others also have influence to some degree.

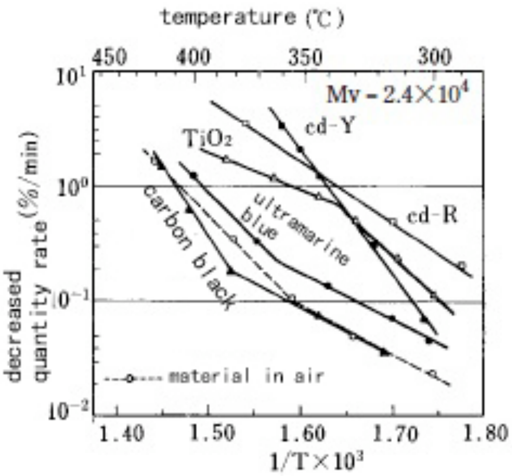


Fig. 4・5・2－11 Influence on decreased quantity rate of the pigment (pigment additive amount: 1.0%)

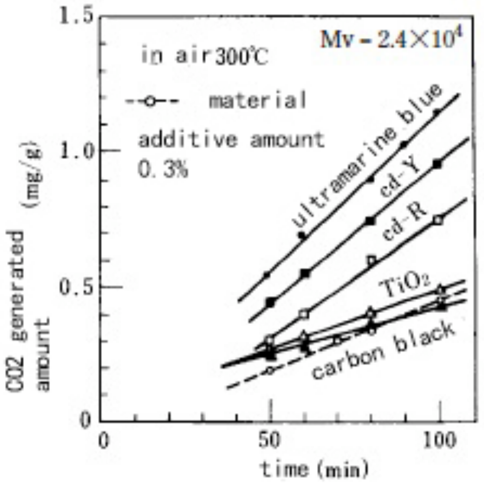


Fig. 4・5・2－12 Influence on CO2 generation of the pigment

Table 4・5・2－2　Influence of metal oxides on heat stability of Iupilon / NOVAREX

Metal oxides	Chemical Composition	pH	Molecular weight Mv x 10^4		Start temperature of decreased quantity (℃)
			0%	1%	
Stannic oxide	SnO_2	4. 2	2. 8	2. 4	340
Lead sulfate	$PbSO_4$	4. 5	2. 8	2. 6	320
Lead chromate	$PbCr_20_3$	5. 4	2. 8	2. 4	306
Lead oxide	Pb_30_4	7. 8	2. 8	2. 2	210
Lead monoxide	PbO	10. 2	2. 8	2. 5	363
Zinc sulfide	ZnS	2. 4	2. 8	2. 4	250
Zinc oxide	ZnO	7. 2	2. 8	2. 7	352
Zinc carbonate	$ZnCO_3$	7. 1	2. 8	1. 9	315
Cadmium sulfate	$CdSO_4$	6. 3	2. 8	2. 7	335
Cadmium sulfite	CdS	6. 3	2. 8	2. 4	340
Cadmium oxide	CdO	9. 4	2. 8	2. 6	315
Cadmium carbonate	$CdCO_3$	7. 0	2. 8	2. 0	280
Aluminum oxide	$A1_2CO_3$	9. 0	2. 8	2. 7	320
Cobalt oxide	CoO	8. 2	2. 8	2. 7	330
Barium sulfate	$BaSO_4$	7. 2	2. 8	2. 7	340
Titanic oxide	TiO_2	6. 8	2. 8	2. 7	343
Copper oxide	CuO	6. 9	2. 8	2. 5	340
Manganese dioxide	MnO_2	6. 6	2. 8	2. 6	350
Ferric oxide	Fe_20_3	6. 4	2. 8	2. 7	320
Chromic oxide	Cr_20_3	5. 5	2. 8	2. 7	358
Cadmium selenide	CdSe	6. 0	2. 8	2. 8	345

As for the molecular weight, the sample melted in nitrogen for 1 hour is used for measurement

As for the start temperature of decreased quantity, the sample added with 1% of the pigment is used for measurement in air.

When adding an organic additive (for example, ultraviolet absorber, stabilizer, antistatic agent, blowing agent, and plasticizer, etc.) to Iupilon / NOVAREX, the one that causes the chemical reaction with polycarbonate can not be used. Also, it is necessary to consider sufficiently not only the reactivity but also the heat stability of the additive to be used because the processing temperature of polycarbonate is high, close to the decomposition temperature of the organic substances at the temperature range above 300℃.
When polycarbonate is heated in vacuum system, it is known that if the decomposition product is removed continuously, the peculiar phenomenon to cause rapidly the gel generation is observed.
The state of gel generation, and the change of soluble part 〔η〕 of methyl chloride are shown in Fig. 4・5・2－13 and Fig. 4・5・2－14, respectively. The generation rate of the decomposition product in this system is indicated in Fig. 4・5・2－15.
It is known that this gel phenomenon is recognized not only in polycarbonate but also in polysulfone, PPE (polyphenylene ether) etc. as shown in Fig. 4・5・2－16.

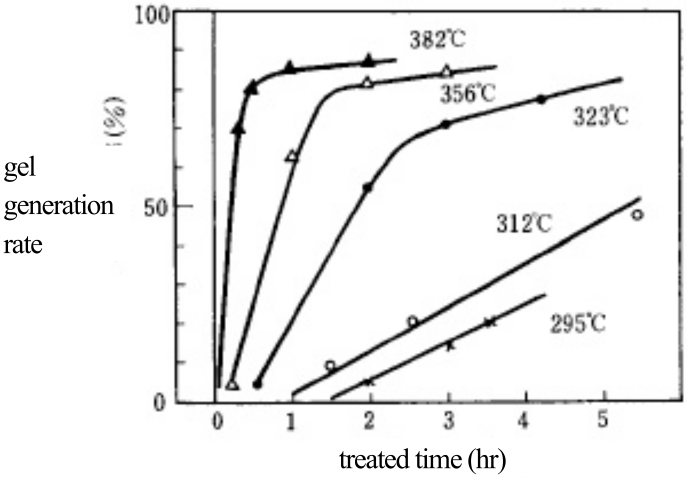


Fig. 4・5・2－13 Gel generation by heating in continuous vacuum system

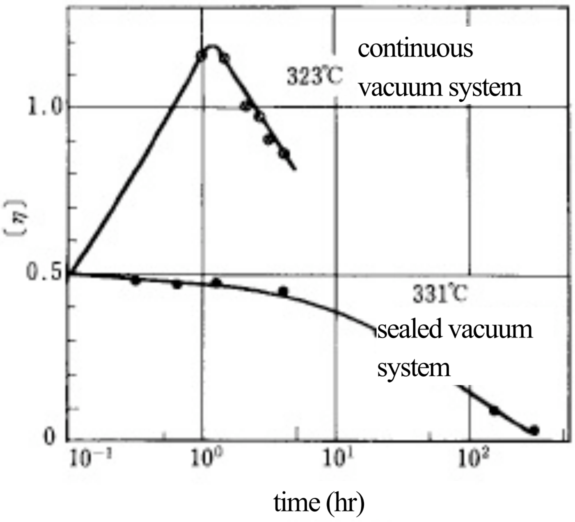


Fig. 4・5・2－14 Change in 〔η〕 by heating in vacuum system

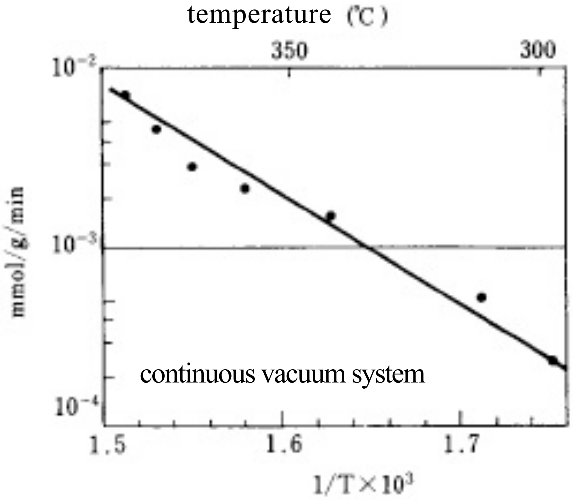


Fig. 4･5･2－15 Generation rate of decomposed gas in continuous vacuum system

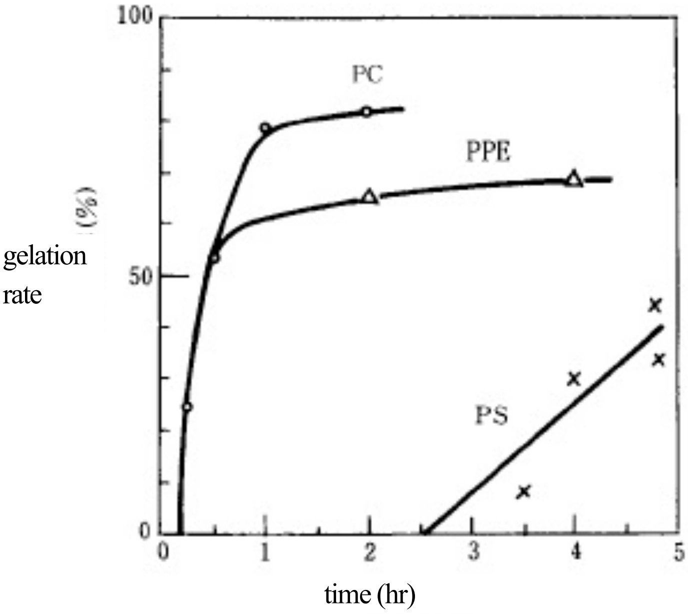


Fig. 4・5・2－16 Gel generation of other resins

The generation of decomposed gas when heating polycarbonate at 700-1200℃ is shown in Fig. 4･5･2－17. CO_2 and CH_4 generation show a constant value regardless of temperature.

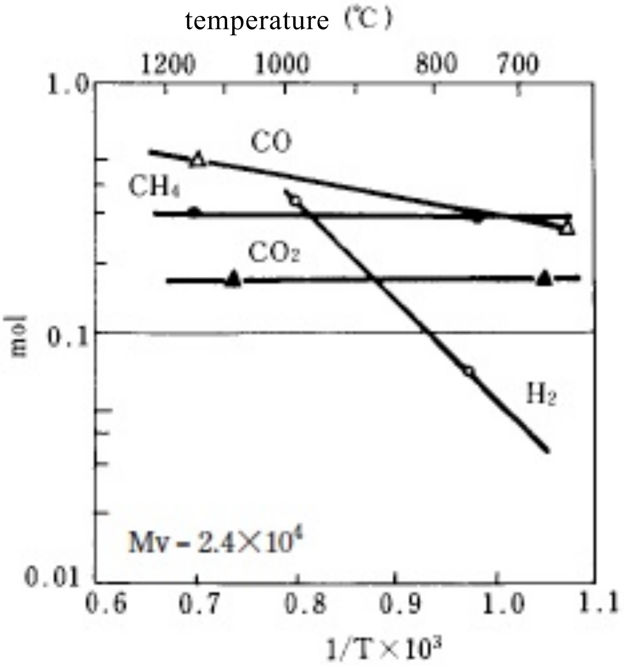


Fig. 4・5・2－17 Generation of decomposed gas at high temperature

4・6 Hot Water Resisting Property

As the bond of the main chain of Iupilon / NOVAREX is an ester bond, hydrolysis takes place gradually and molecular weight decreases when it comes in contact with hot water and steam. At the same time, cracks form with the decrease in mechanical strength after a long time.

The decrease in molecular weight of Iupilon / NOVAREX by treating with hot water is shown in Fig. 4・6ー1. The decrease in molecular weight occurs rapidly by treating at high temperature. Also, the decrease in case of only one surface of the molding contacts with hot water is gentle than the case of the immersion, for example, at 75℃, the treated time when the molecular weight becomes 2.0×10^4 is 3~4 times.

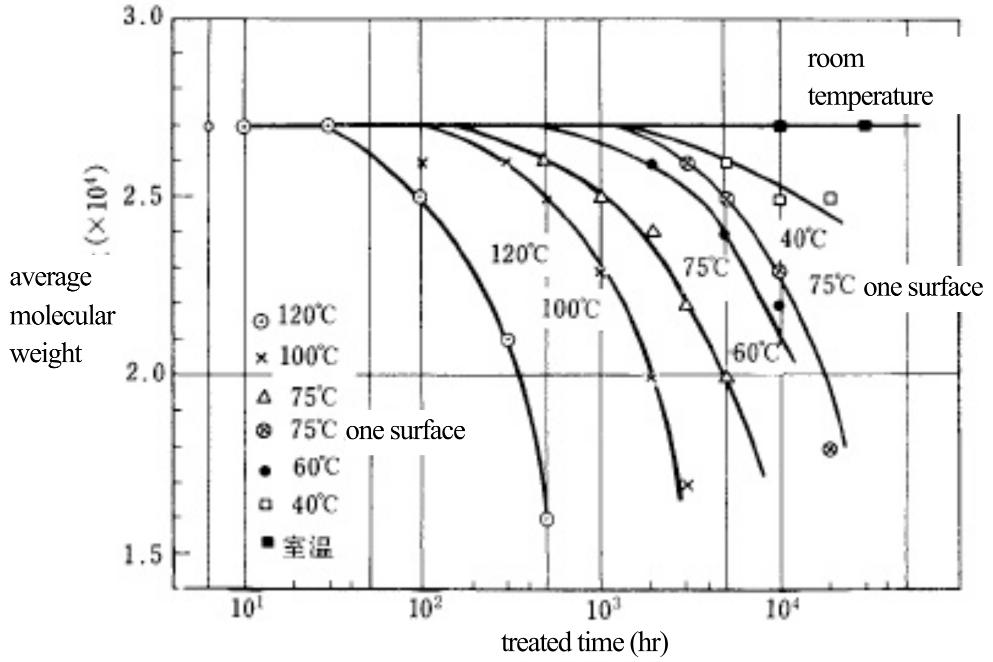


Fig. 4・6ー1 Decrease in molecular weight by treating with hot water

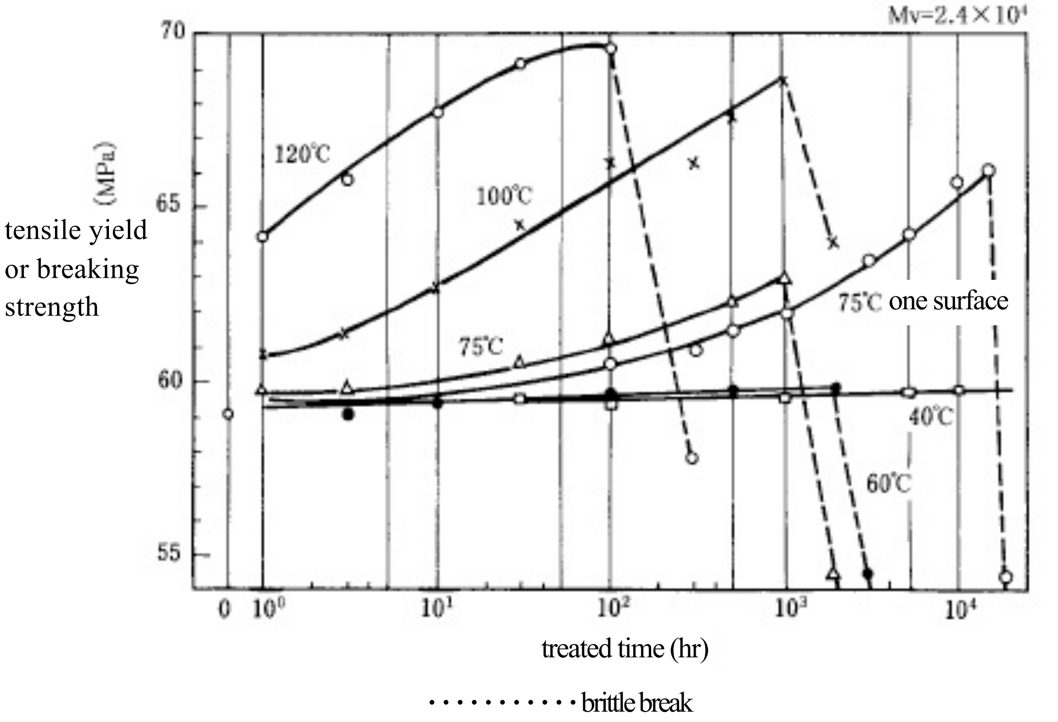


Fig. 4・6ー2 Change in tensile yield or breaking strength by treating with hot water

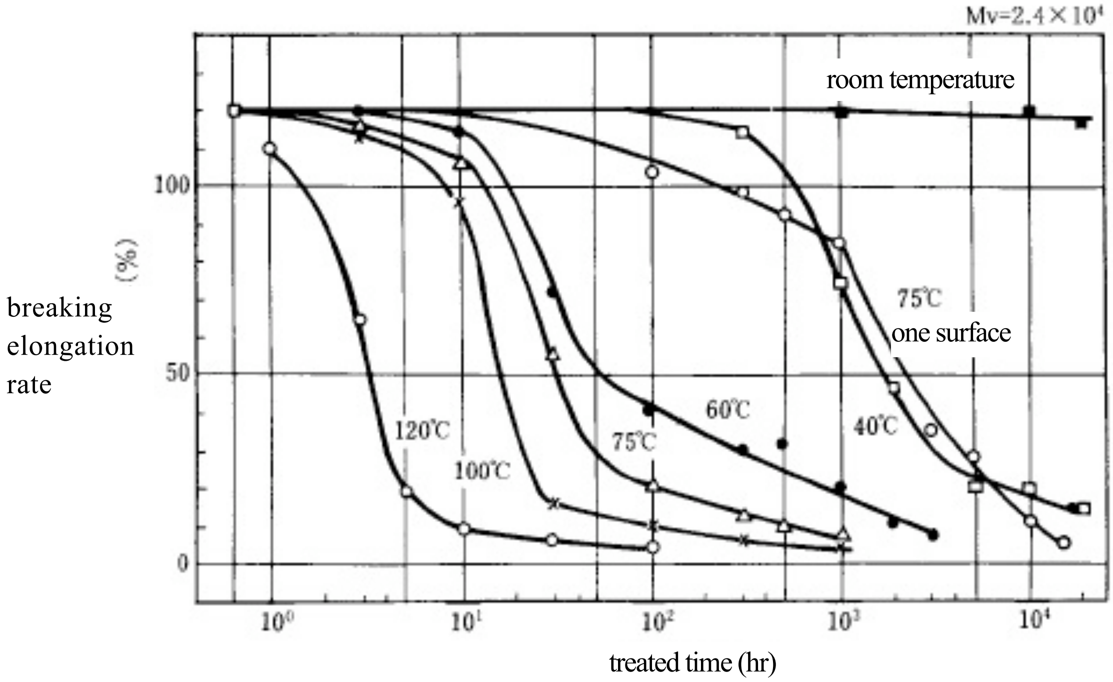


Fig. 4・6―3　Tensile breaking elongation rate by treating with hot water

The tensile properties of Iupilon / NOVAREX treated with hot water show the deterioration by crack generation with decrease in molecular weight as indicated in Fig. 4・6―2 and 3.

The time when ductile breaking moves to brittle breaking is as follows : 100~200 hours at 120℃ (in steam of 98kPa , $1kgf/cm^2$), 1000~2000 hours at 100℃ and 75℃, 2000~3000 hours at 60℃, 20000 hours at 75℃ one surface, above 20000 hours at 40℃. Although the decrease in molecular weight at 75℃ and 60℃ is small but the tensile property is deteriorated. This is due to crack generation.

The deterioration of Izod impact strength is shown in Fig. 4・6―4. The deterioration rate becomes fast compared with the case of dry-heat treatment. For example, as for dry-heat treatment at 100℃, 1000 hours is needed, but only 30~50 hours in case of treating with hot water.

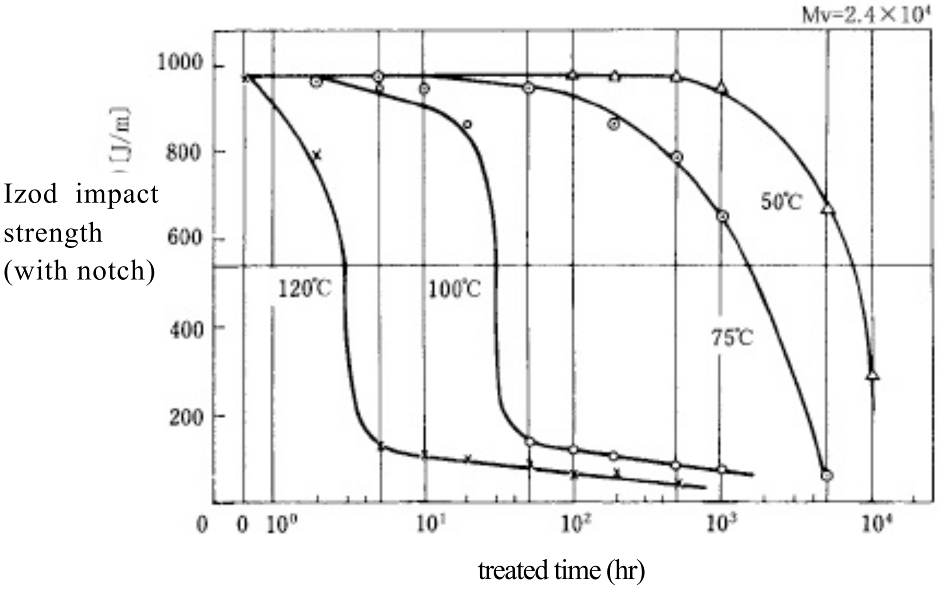


Fig. 4・6―4 Change in Izod impact strength by treating with hot water

4・7 Flammability

A comparison with other resins is shown in Table 4・7－1.

Table 4・7－1 Comparison of flammability with other resins

Polymers	Combustion heat kJ／g（cal／g）	Heat value kJ／g（cal／g）	Generated moisture wt％	Flammability cm／min （in／min）	Oxygen index （％）
Polyethylene	45．9 （10965）	42．8 （10225）	126．6	2．5 （1．0）	17．4
Polypropylene	44．0 （10506）	41．1 （9828）	115．9	2．5 （1．0）	17．4
Polyvinyl chloride	18．1 （4315）	16．8 （4015）	51．3	self-extinguishing	47．0
Tetrafluoro ethylene	4．2 （1004）			nonflammable	95．0
Polymethylmethacrylate （PMMA）	26．2 （6265）	24．6 （5869）	67．8	2．8 （1．1）	17．3
Polystyrene	40．2 （9604）	38．4 （9182）	72．1	2．5—5．1 （1．0—2．0）	18．3
Acrylnitryl・stylene（AS）				2．5 （1．0）	18.1
ABS	35．3 （8424）	33．8 （8066）	61．2	3．3 （1．3）	
Polyether	16．9 （4046）	15．9 （3790）	43．7	2．8 （1．1）	16．2
Ethylcellulose	23．7 （5659）			2．0—3．6 （0．8—1．4）	
Polyamide（nylon）	30．9 （7371）	28．7 （6863）	86．8	self-extinguishing	28．0
Polyphenylether（PPE）				self-extinguishing	30.2
Polysulphone				self-extinguishing	30.4
Polycarbonate	30．5 （7294）	29．4 （7020）	46．8	self-extinguishing	25.0
Copolymerization Polycarbonate （Iupilon N－3）					31.0

The problem should be considered when making plastic flame-resistant does not include only the improvement of its flammability but also the composition, quantity and fuming property of generated gas. In case of Iupilon / NOVAREX, because the composition element is C ・ H ・ O, the generation of toxic gas such as HCI (PVC, Polyvinylidene chloride etc.), NH_3, cyanide (polyamide, ABS, AS etc.), SO_2 (polysulfone etc.) does not occur (Refer to Fig. 4・5・2—17). Also, as for the fuming property, results of various resins are shown in Table 4 ・ 7—2. Polycarbonate has a moderate fuming property in case of ignition combustion, but shows a characteristic with extremely low fuming property in case of burning combustion.

Table 4 ・ 7—2　Fuming property of plastics

Plastics	Thickness mm	Ignition combustion			Burning combustion		
		Dm	Rm	T16（min）	Dm	Rm	T16（min）
Polyvinyl chloride	6.4	660	134	0.8	300	12	3.9
Polyvinylidene chloride	2.8	125					
Polydifluoride vinyl chloride	0.04	0					
Polyfluoro vinyl	0.05	4					
Polystyrol	6.4	660	243	1.3	322	24	7.3
ABS	1.2	660	400	0.6	71	4	4.8
Polymethyl methacrylate（PMMA）	5.6	660	23	2.6	156	60	9.2
Cellulose acetate butyrate	6.4	49	12	5.0	434	45	2.7
Polycarbonate	3.2	174	43	2.1	12	1	
Polyphenylene ether（PPE）	2.0	183					
Polysulphone	1.5	40					
Nylon fiber	7.6	269	105	1.8	320	45	2.8
Acryl fiber	7.6	159	29	0.6	319	49	1.5
Polypropylene fiber	4.6	110	50	1.7	456	60	2.3
Oak	6.4	155	18	3.9	350	34	4.8

Dm：fuming quantity per unit area

Rm：fuming rate

T_{16}：time when Dm becomes 16

4・8　Other Thermal Properties

4・8・1 Brittleness Temperature

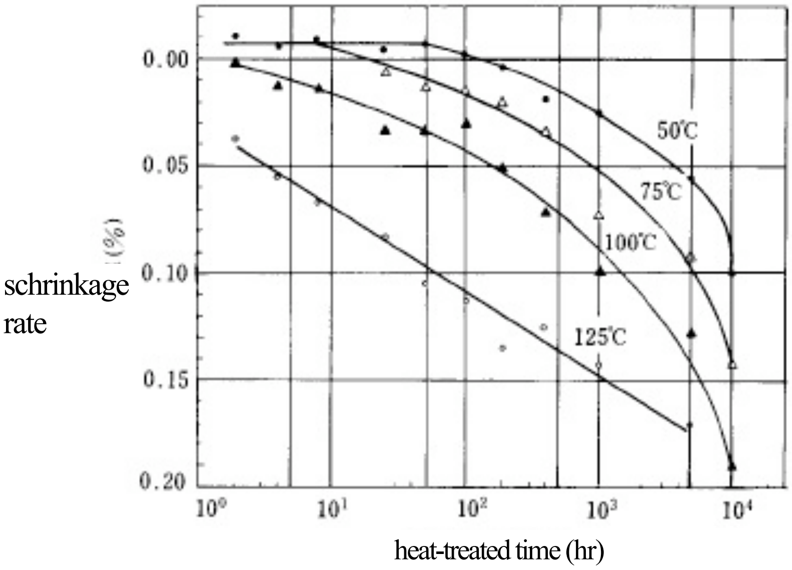
The brittleness temperature of Iupilon / NOVAREX is -135℃.

A comparison with other resins is shown in Table 4・2−1. The low temperature resisting property of Iupilon / NOVAREX is the best among plastics.

4・8・2　Heat Schrinkage

The change of heat schrinkage of Iupilon / NOVAREX when treated in hot air atmosphere is shown in Fig. 4・8・2−1. The heat schrinkage takes place even at low temperature and shows a 0.1~0.2% change. However, such a heat schrinkage also changes in accordance with the molding conditions etc. (Refer to Fig. 4・8・2−2).

The frozen orientation strain is released by macro-Brownian motion of the molecular chain in an atmosphere over 150℃and the schrinkage becomes 5~10%.



（Sample dimension　6.4×12.7×152mm，Mv＝2.2×10^4）

Fig. 4・8・2−1　Change in dimension by heat treating

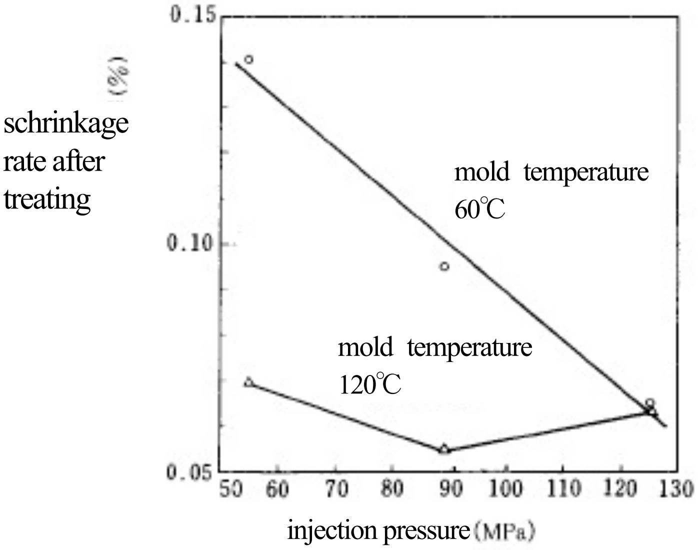


Fig. 4・8・2−2　Relation between injection molding conditions and heat schrinkage

5 . Electrical Properties

5・1 Dielectric Breakdown Strength

The dielectric breakdown strength of Iupilon / NOVAREX is 18~22MV/m by ASTM-D149, thickness 1.6mm. The characteristics of test piece thickness and temperature are shown in Fig. 5・1－1 and Fig. 5・1－2, respectively.

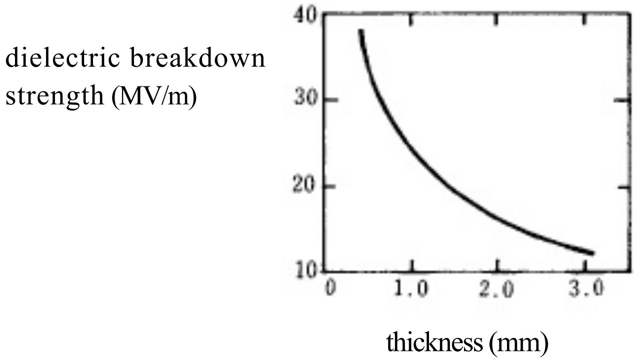


Fig. 5・1－1 Dielectric breakdown strength – thickness characteristic of Iupilon / NOVAREX
(room temperature, in oil, short time voltage increase)

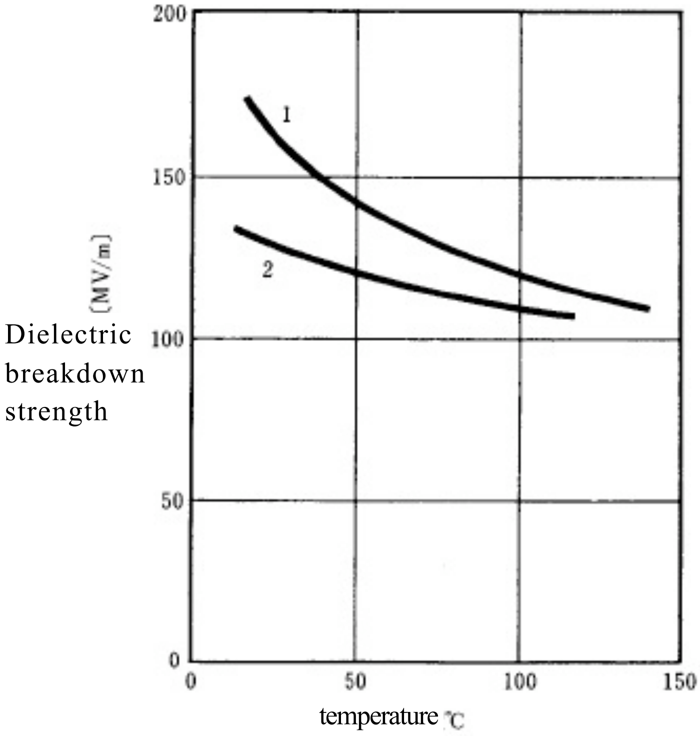


Fig. 5・1－2 Dielectric breakdown strength – temperature characteristic of polycarbonate film
(1: Polycarbonate, 2: Cellulose acetobutyrate)

Table 5・1-1

	Impulse breakdown voltage
Iupilon rod	180－190KV
Epoxy laminated rod	140－150
Phenol laminated rod	130－135
Melamine laminated rod	120－130

The impulse breakdown voltage of Iupilon / NOVAREX is shown in Table５・１－１.

A comparison with other resins is shown in Fig. 5・1—3.

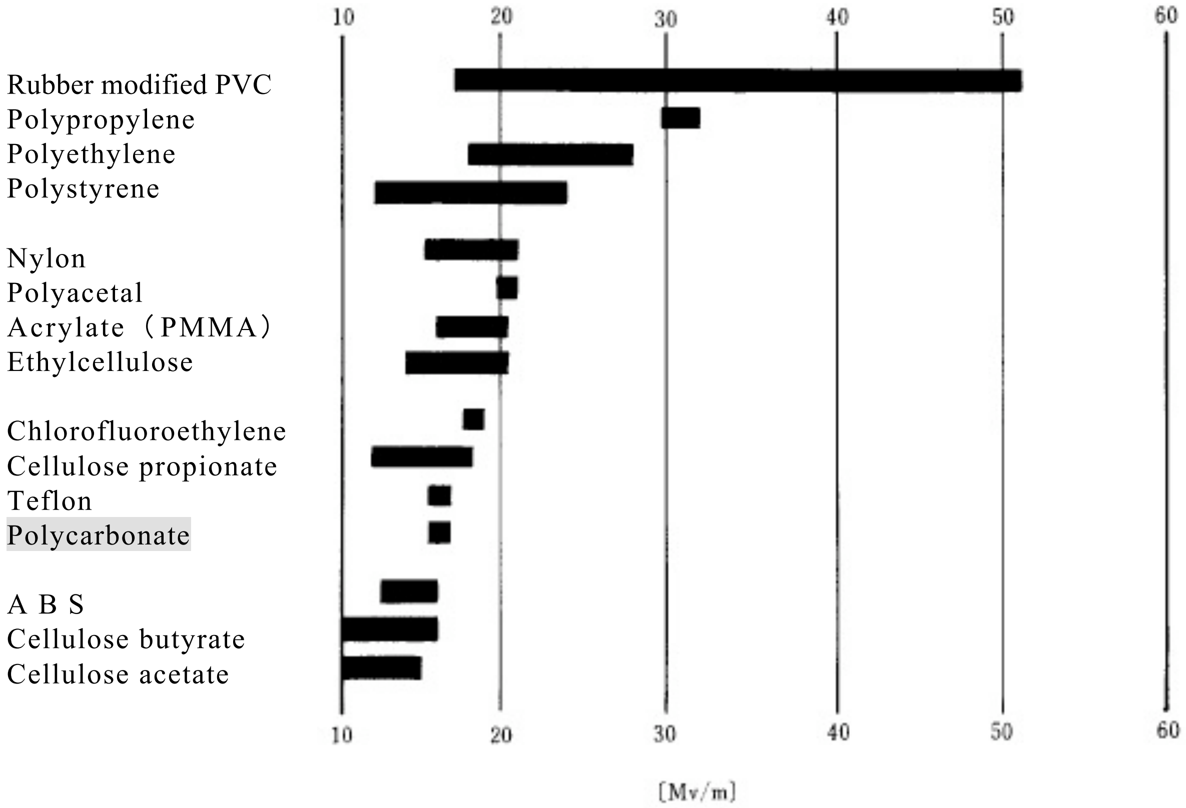


Fig. 5・1—3　Dielectric breakdown strength of various resins
(short time voltage increase: ASTM-D149)

5・2　Insulation Resistance

The volume resistivity of Iupilon / NOVAREX is

ASTM-D257-58

$-30\sim-3$℃	$>10^{17}\,\Omega\cdot\mathrm{cm}$
23℃	2.1×10^{16}
125℃	2.0×10^{14}

The surface resistivity of polycarbonate is

In the dry state	$\geqq10^{15}\,\Omega$
Immersed in water for 4 hours （DIN53482, φ80, 2mm thickness）	$\geqq10^{15}\,\Omega$

A comparison of volume resistivity with other resins is shown in Fig. 5・2－1.

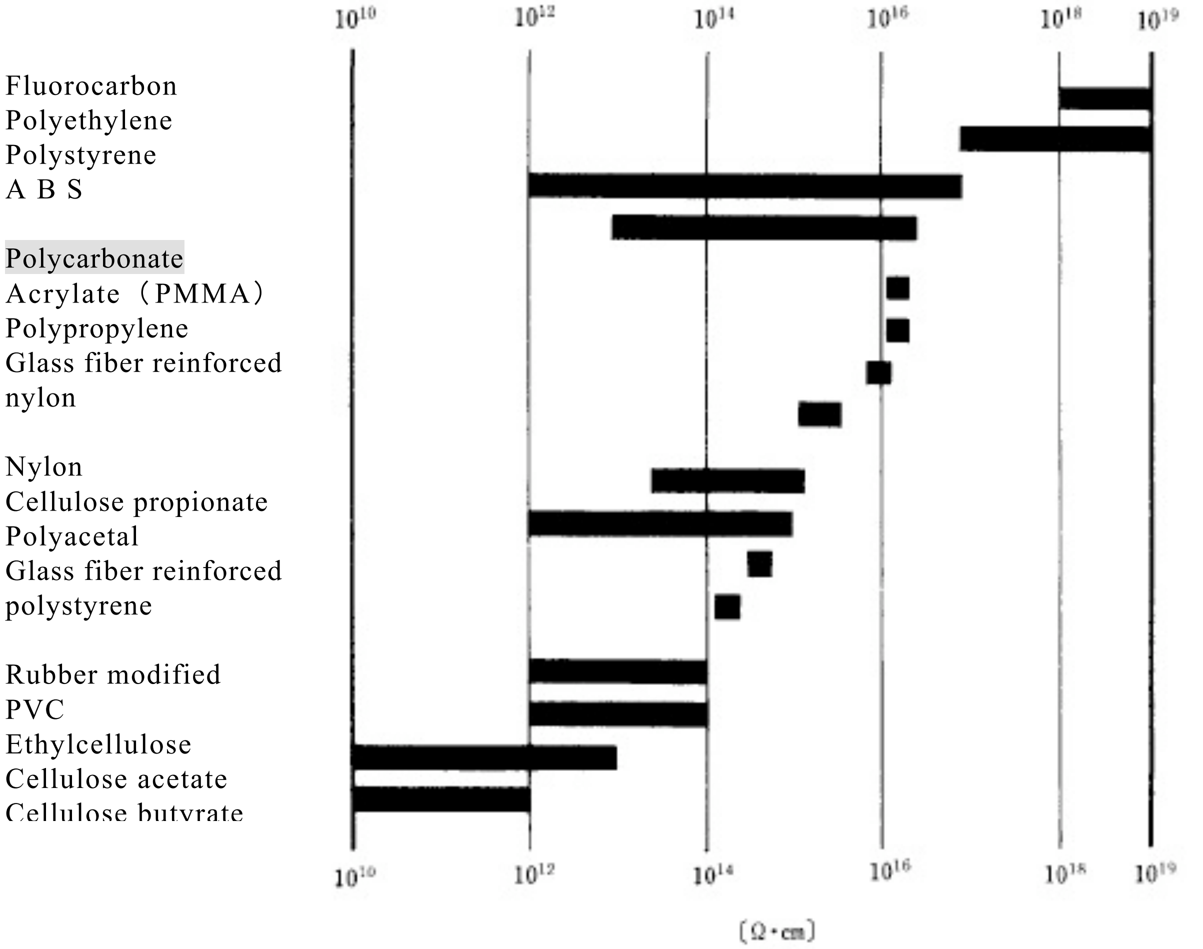


Fig. 5・2－1 Volume resistivity of various resins (ASTM-D257)

5・3 Dielectric Constant and Dielectric Dissipation Factor

The dielectric constant and dielectric dissipation factor of Iupilon / NOVAREX are

ASTM-D150-54T, 50Hz, normal temperature

Dielectric constant	26.5PF/m(3.0)
Dielectric dissipation factor	0.0009

The temperature characteristics and frequency characteristics of dielectric constant and dielectric dissipation factor of Iupilon / NOVAREX are shown in Fig. 5・3－1 and Fig.5・3－2, respectively.

Also, a comparison of dielectric constant with other resins is shown in Fig. 5・3－3.

Resins with low dielectric constant are suitable for use as insulator and those with high dielectric constant are suitable for use as capacitor. Iupilon / NOVAREX can be used for both applications. Also, its feature is that change due to temperature and frequency is small.

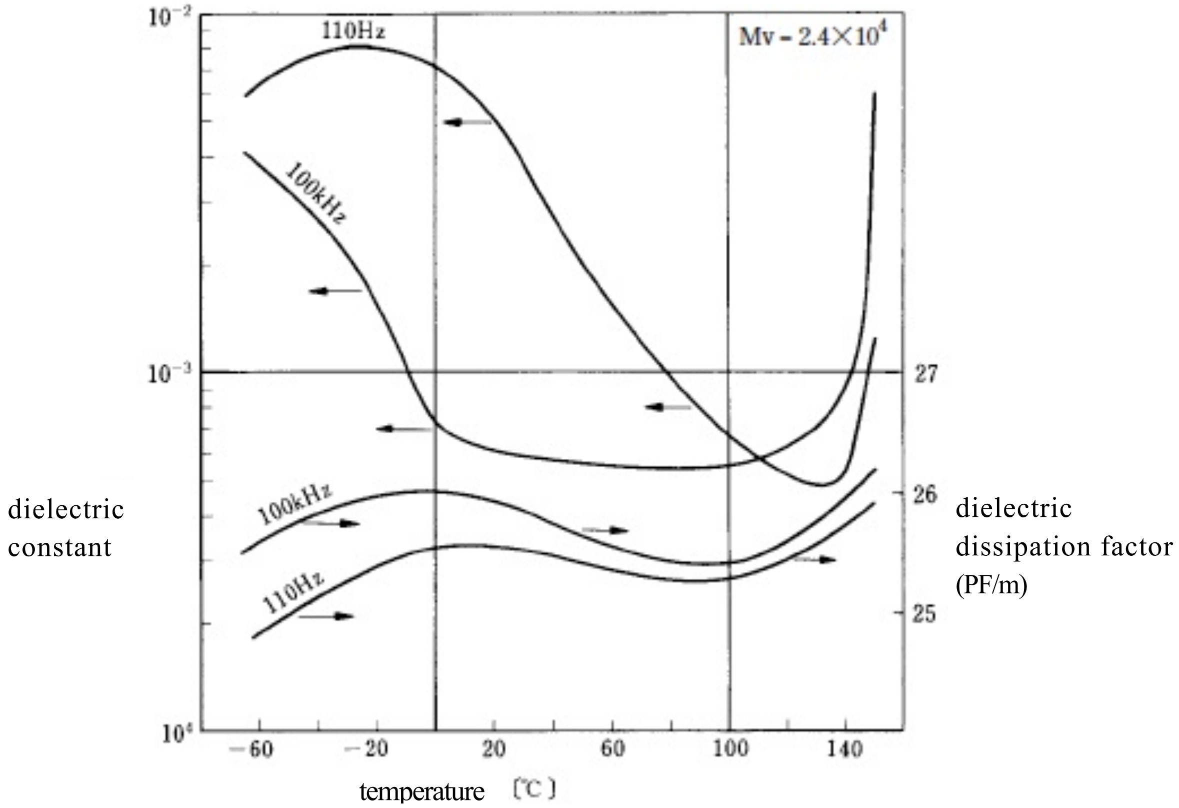


Fig. 5・3－1 Temperature characteristics of dielectric constant and dielectric dissipation factor of Iupilon / NOVAREX

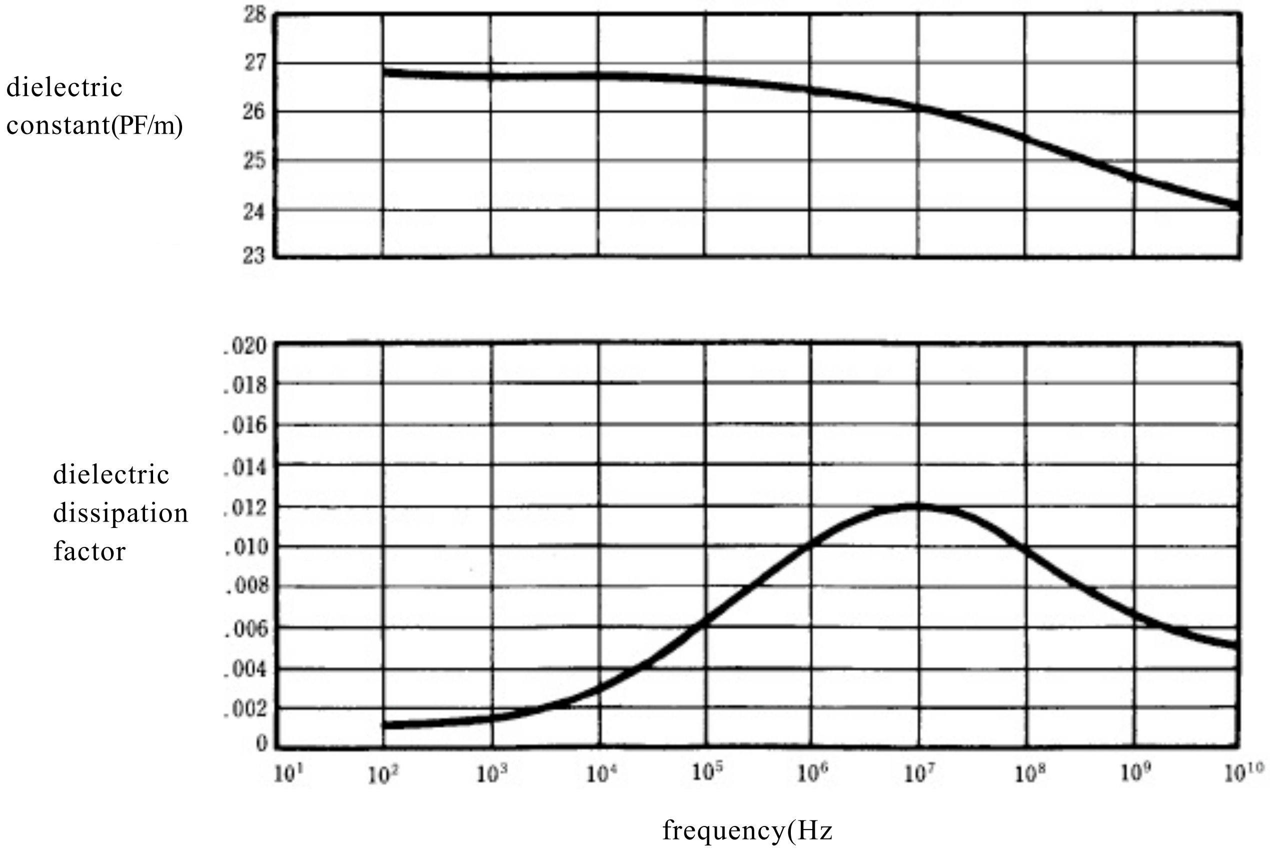


Fig. 5・3－2 Frequency characteristics of dielectric constant and dielectric dissipation factor of polycarbonate

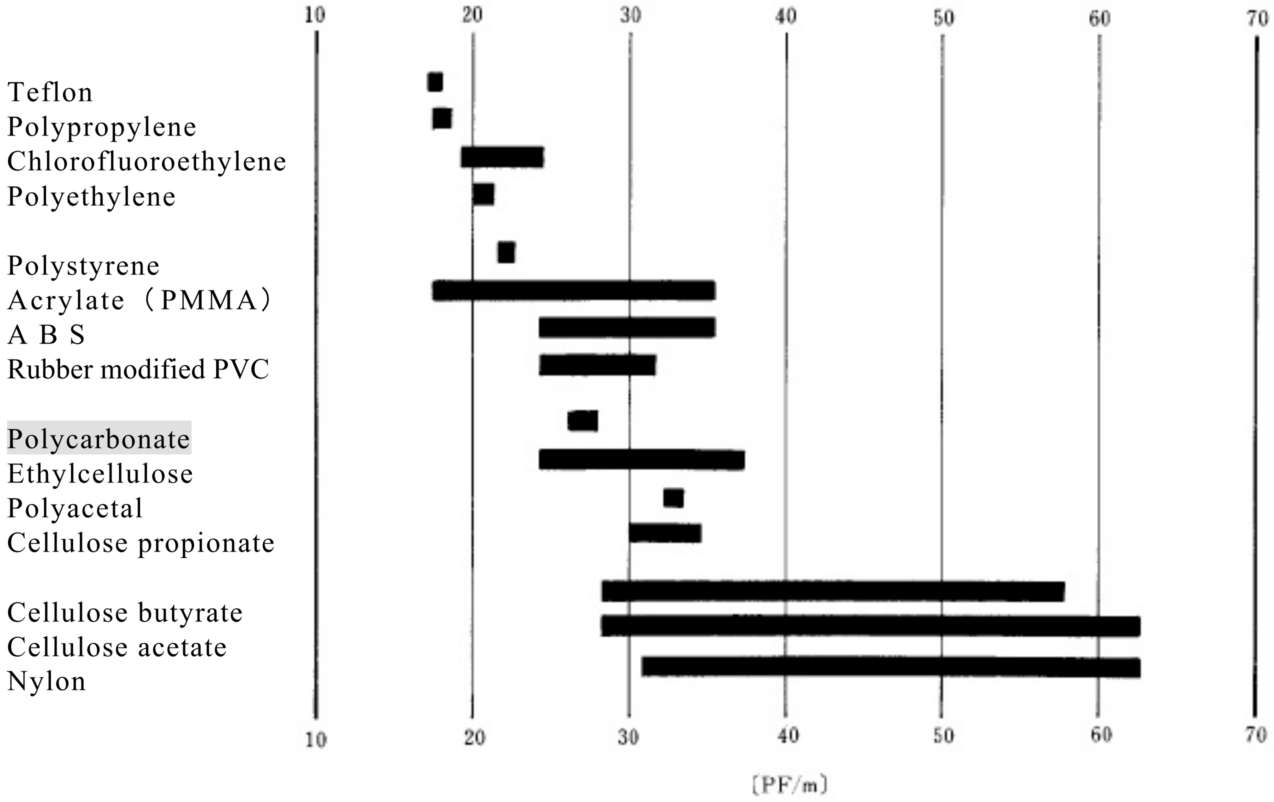


Fig. 5・3—3 Dielectric constant of various resins (ASTM-D150, frequency 60~ x 10^6Hz)

5・4 Other Electrical Properties

5・4・1 Arc Resistance

The arc resistance of Iupilon / NOVAREX based on ASTM-D495 is

Tungsten electrode 100~120sec.
Stainless steel electrode 10~11sec

The arc resistance of Iupilon / NOVAREX after immersing in water at room temperature for 100 hours is

Tungsten electrode 93sec.

The influence of carbon black addition on the arc resistance of Iupilon / NOVAREX, and the influence of colorant addition are shown in Table 5・4・1—1 and Table 5・4・1—2, respectively.

Table 5・4・1—1 Influence of carbon black addition on the arc resistance of Iupilon / NOVAREX (use of tungsten electrode)

$Mv = 2.4 \times 10^4$

Additive rate of carbon black〔wt%〕	0	0. 01	0. 03	0. 1	0. 3	0. 6	1. 0	3. 0	6. 0
Arc resistance〔sec〕	110	116	120	119	120	113	98	58	38

Table 5・4・1－2 Influence of colorant addition on the arc resistance of Iupilon / NOVAREX
（addition of 0.1wt% colorant, use of tungsten electrode）

Mv＝2． 4×10^4

Colorants	Arc resistance 〔sec〕	Colorants	Arc resistance 〔sec〕
Black	117	Green series	96
Green series	121	Cyanine blue	104
Orange series	110	Orange series	121
Blue series	119	Yellow series	116
Yellow series	119	Orange series	118
“	123	Pink series	118
Red series	107	Fluorescent pigment	122
“	118	Titanium white	119
Green series	109		

The arc resistance of various thermoplastic resins is shown in Table 5・4・1－3.

Table 5・4・1－3　Comparison of arc resistance, use of tungsten electrode

Polymers	Arc resistance	
	〔sec〕	Breakdown status ＊
Polycarbonate	110	A
Polyacetal	＞240	D
66 Nylon	＞140	C
Polypropylene	＞140	E
6 Nylon	140	B
Polyethylene	＞130	E
Polystyrene	＞130	E
PBT（composite reinforced）	125	A
12 Nylon	＞120	C
Polymethylmethacrylate	＞120	E
AS	＞120	B. E.
Polyethyleneterephthalate	120	A
PC・ABS blended product	112	A
Ionomer	＞111	B. E.
High impact strength polystyrene	＞95	E
ABS	93	A
Polysulphone	78	A
Modified PPE	67	A

＊ Breakdown status
A: arc extinction by carbonization
B: arc extinction by inflammation
C: burn, but arc does not extinct
D: leave a hole due to melting but arc does not ectinct
E: burn and leave a hole but arc does not extinct

5・4・2 Tracking Resistance

The tracking resistance of polycarbonate is

IEC112（platinum electrode）240~260
IEC112（brass electrode） 135~150

5・4・3 Corona Resistance

The corona resistance of polycarbonate is shown in Fig. 5・4・3－1. It indicates infinite endurance at about 30MV/m.

The corona inception voltage of Iupilon / NOVAREX is shown in Table 5・4・3－1.

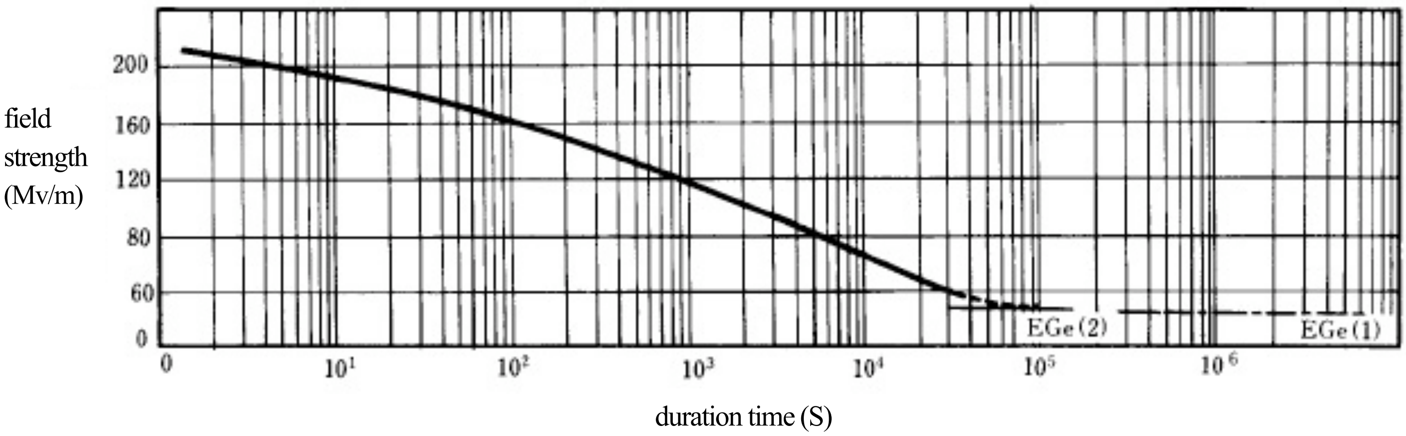


Fig. 5・4・3－1 Relation between dielectric breakdown voltage (frequency 50Hz) and exposure time of polycarbonate

Table 5・4・3－1

	Corona inception voltage (kV)	Flashover voltage (kV)
Iupilon / NOVAREX rod	45－50	Above 50
Epoxy laminated rod	50	Above 50
Phenol laminated rod	30－50	Above 40－50
Melamine laminated rod	30－50	Above 50

6. Chemical Properties

6・1 Rate of Water and Moisture Absorption

The rate of water absorption is

ASTM－D570, after 24 hours in water 0. 23~0. 26%

The rate of water and moisture absorption of Iupilon / NOVAREX is as shown in Fig. 6・1－1.

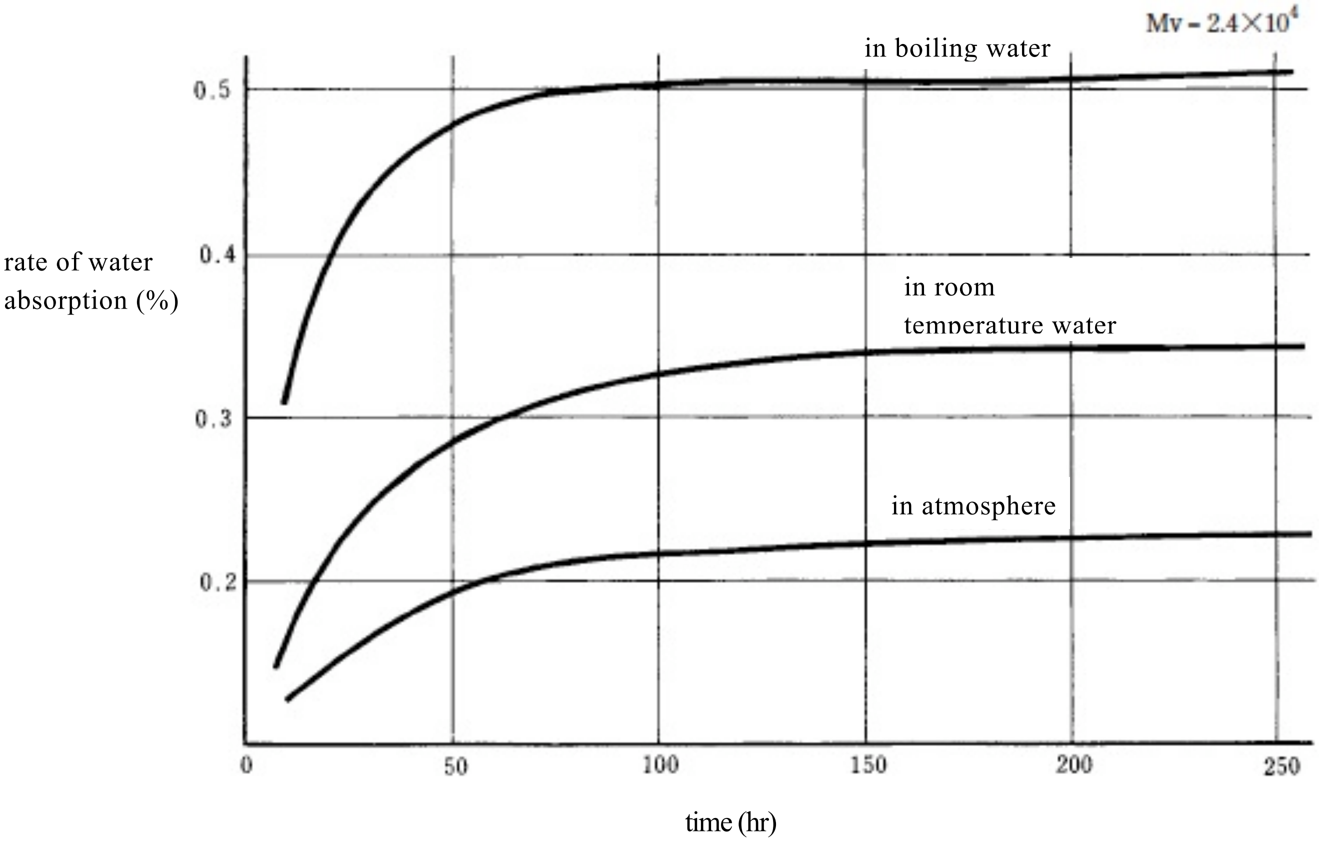


Fig. 6・1－1 Water absorption curve of Iupilon / NOVAREX (ASTM-D570)

Also, the rate of water absorption measured according to JISK6771-1958 was

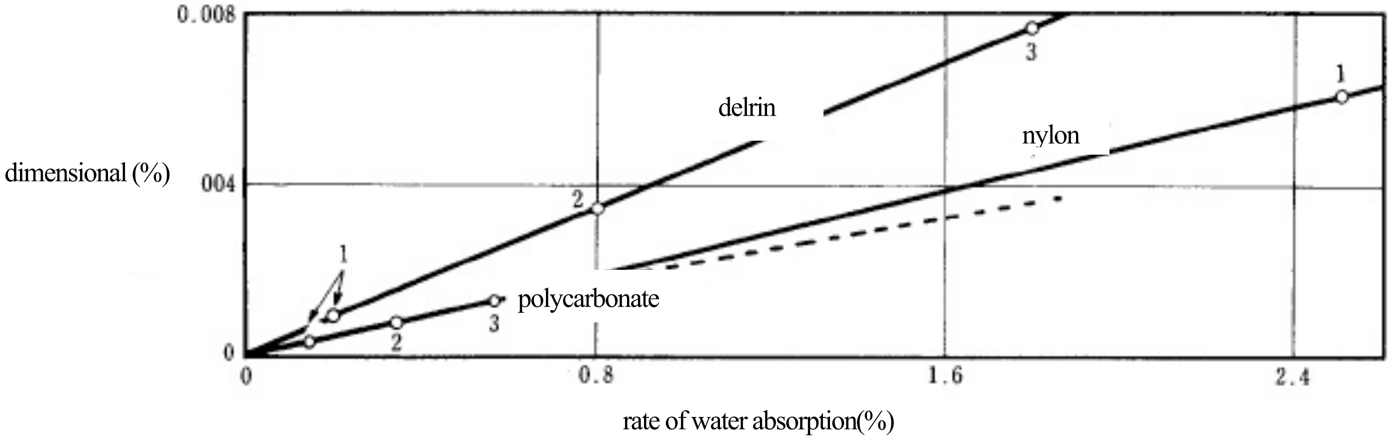
After 24 hours in 50℃water	0.29%
After 24 hours in 75℃water	0.39%

This method of measuring the rate of water absorption is not necessarily based on rate of water absorption of zero.

In view of this, if the moisture of these moisture-absorbed samples is determined by the Karl Fischer method, the coefficient of water absorption becomes about 0.05~0.10% larger than the above values.

The dimensional change of polycarbonate by water and moisture absorption is as shown in Fig. 6・1－2.

A comparison with other resins is shown in Table 6・1－1, from which it can be seen that the rate of water absorption of Iupilon / NOVAREX is very small and consequently, one of its features is that dimensional change due to this is very small.



1: room temperature, 50%RH, 2: in room temperature water, 3: in boiling water
Fig. 6・1－2 Dimensional change by water absorption

Table 6・1－1 Rate of water absorption of various resins
ASTM－D570 (after 24 hours)

Name of substances	Rate of water absorption (%)
Low density polyethylene	＜0.01
Polycarbonate	0.23
Rubber modified PVC	0.07~0.2
Cellulose propionate	1.2~2.8
High impact strength ABS	0.3
High impact strength ethylcellulose	0.8~2.0
Ethylcellulose	1.2~2.0
Soft cellulose acetate	2.3~6.5
Soft cellulose butyrate	0.9~1.3
Rigid cellulose butyrate	1.3~1.8
Cellulose acetate	1.9~4.0
Teflon	0.00
Glass fiber reinforced nylon	0.7~1.4
Polyethylene	0.04~0.08
ABS	0.2
Rigid cellulose acetate	1.6~3.8
Nylon	1.2~2.3
Acrylate	0.2~0.4
Polyacetal	0.41
Polypropylene	＜0.01

6・2 Gas Permeability

Water vapor permeability of Iupilon film is as shown in Table 6・2−1.

Table 6・2−1

Film thickness (mm)	Testing method	Rate of water vapor permeability (g／㎡・day)
0.20	JIS-Z 0208, tempt. 40℃, humidity90%	23.3
0.08	ASTM-E 96—53T, tempt. 50℃, humidity50%	46−57
0.05	“ASTM-E 96—53T, tempt. 50℃, humidity 50%	69
0.02	JIS-Z 0208, tempt. 40℃, humidity90%	195

Gas permeability of Iupilon is as shown in Table6・2−2 and Fig. 6・2−1. The relation between gas permeability constant and 1/T is shown by the straight line but it has a refractive point between 0~20℃ in case of gas with relatively big constant.

Also, the relation between gas permeability of Iupilon and sample thickness is as shown in Table 6・2−3. It depends on the kind of gas but shows almost a constant value until the thickness of 300μm except for CO_2.

Table 6・2−2 Gas permeability of Iupilon film （ASTM−D1434）

Temperature (℃)	Gas permeability constant*				
	H_2	He	N_2	O_2	CO_2
90			20. 6		
80			16. 2		
70			12. 3	46. 4	
60	533.	315.	9. 7	39. 2	210.
50	352.	237.	6. 1	31. 9	160.
40	208.	197.	4. 9	23. 8	127.
30	165.	144.	3. 2	18. 1	103.
20	120.	110.	2. 4	14. 3	72.
0	62.	77.	1. 4	8. 4	48.
−10	47.	48.	0. 8	5. 8	31.
−20			0. 4	4. 0	
−25				3. 3	
−30	34.	34.		2. 9	19.
−35	24.	25.		2. 3	11.
−40	17.	18.		2. 1	5. 0
−45	12.	13.		1. 3	2. 1
−50	7.	8.		1. 0	1. 3
−55				0. 9	
−60				0. 8	

* Unit cm^3・cm/cm^2・s・cmHg・10^{11}, pressure difference 1 atm, thickness 50μm

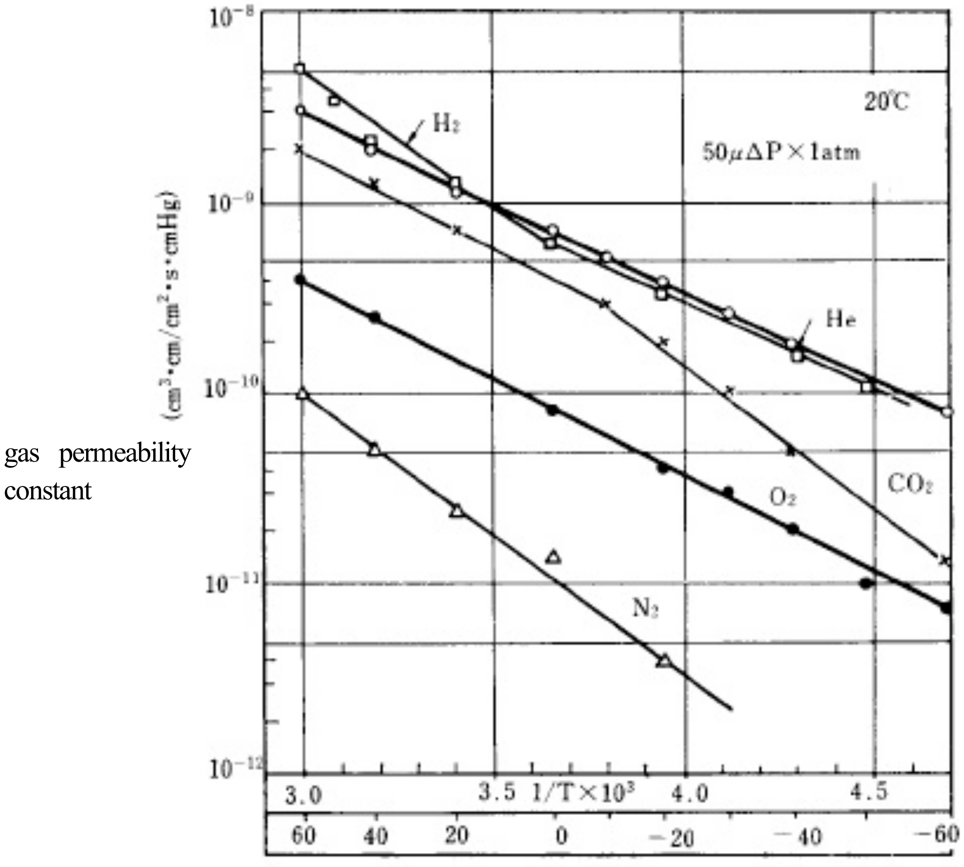


Fig. 6・2－1 Gas permeability of Iupilon

The relation between gas permeability of Iupilon and thickness is as shown in Table 6・2－3.

Table 6・2－3 Relation between gas permeability of Iupilon and thickness

Thickness (μm)	Gas permeability constant*			
	H_2	N_2	O_2	CO_2
50	120.	2.4	14.3	72
100	109.	2.5	14.2	56
200	105.	2.3	12.2	26
300	105.	2.4	12.8	24
600	114.		9.1	

＊ Unit $cm^3 \cdot cm/cm^2 \cdot s \cdot cmHg \cdot 10^{11}$, pressure difference 1 atm, tempt. 20℃

The values of water vapor and gas permeability for other resins are shown in Table 6・2－4.

Table 6・2－4

	Rate of water vapor permeability ＊	Gas permeability constant ＊＊			
		H_2	O_2	N_2	CO_2
Polyethylene	4. 3	10. 07	3. 47	1. 22	12. 5
Mylar	9. 5	0. 80	0. 04	0. 008	0. 20
Polyvinyl chloride	22. 1	3. 8			1. 78
Nylon	43. 8	1. 0	0. 78	0. 28	0. 31
Polystyrene	45	33. 1	5. 8	2. 79	10. 5

＊ ASTM・E96－53T, temperature 37. 8℃, water in cup, outside humidity 0%, unit g/m2・day/0. 1mm

＊＊Temperature 30℃, unit $cm^3 \cdot cm/cm^2 \cdot s \cdot cmHg \cdot 10^{10}$

＊

6・3 Chemical Resistance

Chemical resistance of Iupilon / NOVAREX at room temperature and 75℃ is shown in Table 6・3－2.

As Iupilon / NOVAREX is a polyester, there is a limit to resistance against alkaline chemicals as they cause hydrolysis of the ester bond. As a general rule, it has a strong tendency of swelling and dissolving in aromatic hydrocarbons and chlorinated hydrocarbons.

Also, the ester bond is broken at high temperature by alcohols and phenols.

At a high temperature (60~100℃), it is degraded when left standing for a long time even in pure water, as mentioned in paragraph 4・6 and in view of this, the effect on chemical resistance at 75℃ can not be overlooked.

As a general rule, the phenomenon of stress cracking or solvent corrosion is present in plastics, by which cracks are formed when it comes in contact with some solvent or its vapor under stress.

Precaution must be taken as this phenomenon is also present in Iupilon / NOVAREX. Solvents to which Iupilon / NOVAREX is particularly sensitive when under stress are carbon tetrachloride, hexane, acetone and alcohols, and some examples are given in Fig. 6・3－1.

Also, the limiting tensile strain at which stress cracking is produced by carbon tetrachloride, acetone and hexane is 0.5, 0.35 and 0.8%, respectively, while compression strain does not cause such stress cracking.

In addition, it is known that wide-range substances, for example plasticizers, grease, rubber, and various oils etc. also cause the solvent corrosion, and some examples are given in Table 6・3－1.

It is necessary to test the solvent corrosivity of the used substance at the time of design of practical articles.

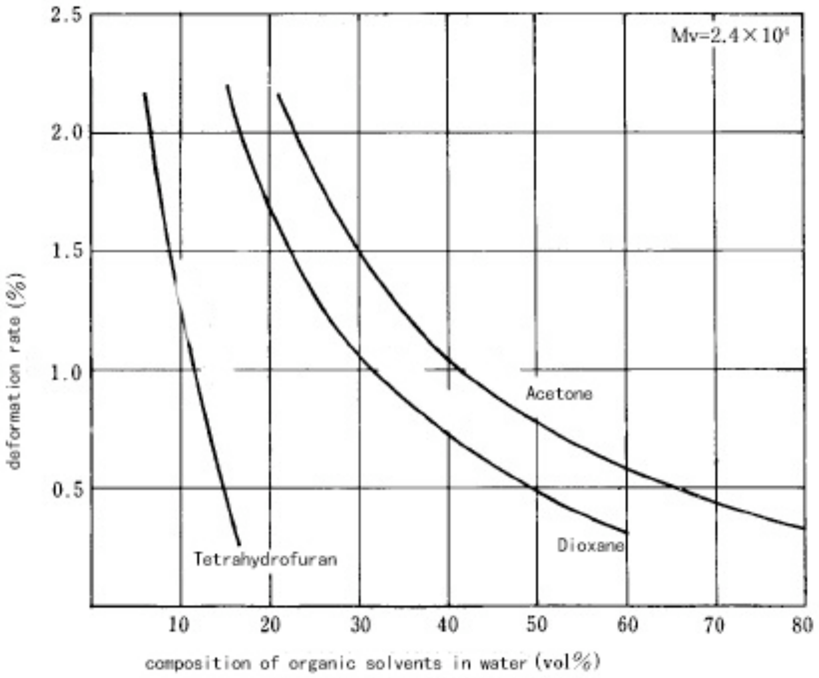


Fig. 6・3－1 Solvent cracking curve under stress of Iupilon / NOVAREX
(Tempt. 25℃, test piece 152×12． 7×6． 4mm)

A combination of flexural strain that does not produce crack and solvent composition was plotted for the case the product was immersed in mixed solvents of various compositions for 1 minute in a condition various flexural strains were given.

Table 6・3－1 Solvent corrosion of Iupilon 〔Unit MPa (kgf/cm^2)

Substances	Solvent corrosion		Substances	Solvent corrosion	
	R. T	75℃		R. T	75℃
Flexible PVC（with 60% plasticizer）	7． 8	3． 9 (40)	Cutting oil（Komirogen）	29． 4 (300)	3． 9 (40)
Grease（Albania No． 2）	(80) 33． 3	9． 8 (100)	Cutting oil（Komirogen 30% aqueous solution）	29． 4 (300)	7． 8 (80)
Grease（Albania No． 2 low temp. use）	(340)	15． 7	Cutting oil（Dromas oil B）	29． 4 (300)	3． 9 (40)
Grease（beacon No． 325）	8． 8 (90)	(160) 15． 7	Cutting oil（Dromas oil 60%aqueous solution）	29． 4 (300)	7． 8 (80)
Grease（silinon SH7071）	33． 3 (340)	(160)	Salad oil	16． 7 (170)	7． 8 (80)
Natural rubber	25． 5 (260)	7． 8 (80)	Antifungal oil（PA－50）	29． 4 (300)	16． 7 (170)
Neoprene rubber（A）	24． 5 (250)	7． 8 (80)	Antifungal oil（Taiana）	29． 4 (300)	19． 6 (200)
Neoprene rubber（B）	8． 8 (90)	3． 9 (40)	Antifungal oil（CRC－36）	19． 6 (200)	8． 8 (90)
Butyl rubber	21． 6 (220)	7． 8 (80)	Sealant（A）	21． 6 (220)	3． 9 (40)

Ethylene propylene rubber	12. 7 (130)	3. 9 (40)	Sealant（B）	29. 4	7. 8 (80)
Silicon rubber（A）	32. 4 (330)	15. 7 (160)	Epoxy cast agent	(300) 20. 6	3. 9 (40)
Silicon rubber（B）	25. 5 (260)	15. 7 (160)	Silicon cast agent	(210)	11. 8 (120)
Rock materials	3. 9 (40)	3. 9 (40)	Blank	39. 2 (400)	22. 6 (230)

Testing method: Let the substance touch the part where maximum flexural stress is generated by constant strain method, and leave it at normal temperature for 48 hours, at 75℃ for 3 hours, then calculate the strain quantity that crack is not generated and convert it to stress.

Table 6・3−2 Chemical resistance of Iupilon / NOVAREX at room temperature and 75℃

Size of test piece : 63.5mm length, 12.7mm width, 3.2mm thickness

Strength before tes: Tensile strength 58.1MPa (592khf/cm2), Izod impact strength (with notch) 910J/m

Figures in ( ) indicate values at 75℃ and all are values after immersion for 30 days.

Name of chemicals	Change in weight %	Change in tensile strength %	Impact value J／m	Change in appearance
Inorganic salts				
Sodium chloride 15%	+0. 14	−4. 4	890	No change
(15%)	(+0. 22)	(+1. 52)	(−)	Small number of cracks
Sodium sulfide 15%	+0. 13	−5. 4	930	No change
(15%)	(+0. 15)	(+3. 55)	(−)	Haze on surface, small number of cracks
Potassium chloride 15%	+0. 14	−3. 2	950	No change
Potassium nitrate 15%	+0. 15	−3. 6	920	No change
1 (15%)	(+0. 21)	(+1. 18)	(−)	Small number of cracks
Potassium dichromate 15%	+0. 15	−2. 9	950	No change
(15%)	(+0. 31)	(−0. 7)	(−)	Small number of cracks
Calcium chloride 15%	+0. 14	−4. 4	930	No change
(15%)	(+0. 15)	(+0. 7)	(−)	Small number of cracks
Sodium sulfate 10%	(+0. 25)	(+1. 5)	(−)	Small number of cracks
Inorganic acids				
Hydrochloric acid 35%	+0. 13	−8. 5	56	Cracks
(15%)	(+0. 18)	(+2. 4)	(−)	Cracks
10%	+0. 10	−2. 7	920	No change
(5%)	(+0. 38)	(+1. 5)	(−)	Cracks
Sulfuric acid 98%	−	−	−	Whiten, dissolve
90%	+5. 16	−1. 9	890	Milk white
— 85%	−0. 17	−5・4	910	No change
80%	−0. 30	−4. 1	920	No change
(80%)	(−0. 78)	(+1. 5)	(−)	No change
50%	−0. 13	−3. 0	860	No change
(50%)	(−0. 10)	(+3. 6)	(−)	No change
10%	−0. 13	−6. 0	880	No change′
(10%)	(+0. 19)	(+0. 8)	(−)	No change
Nitric acid 60%	+1. 41	−9. 2	920	Discolor to yellow
(60%)	(−)	(−)	(−)	Shape destroyed

30%	+0. 25	−6. 6	640	Discolor to yellow
(30%)	(+1. 06)	(−7. 9)	(−)	Opaque, yellow
10%	+0.14	−2. 0	910	No change
(10%)	(+0, 33)	(0)	(−)	Transparent yellow
Orthophosphoric acid 100%	−0. 25	+0. 8	960	No change
(100%)	(−0. 12)	(+3. 2)	(−)	Transparent light yellow
10%	+0. 09	−3. 4	900	No change
(10%)	(+0. 24)	(+2. 7)	(−)	Cracks

Name of chemicals	Change in weight %	Change in tensile strength %	Impact value J／m	Change in appearance
Chromic acid 10%	+0. 25	−3. 7	950	No chang
Hydrogen fluoride conc.	+1. 42	−9. 3	1000	No charge
Sulfuric acid 50 vol% Nitric acid 50 vol%	+5. 02	−19. 0	88	Dissolve
Sulfuric acid 300g Chromic anhydride 150g Water 1.5l	+0. 14	−4. 4	920	No change
Inorganic alkali				
Sodium carbonate 15%	+0. 13	−3. 2	870	No change
(15%)	(−0. 79)	(+2. 0)	(−)	Cracks
Sodium hydroxide (10%)	(−2. 92)	(−1. 4)	(−)	Surface haze, cracks
5%	+0. 03	−4. 4	950	No change
(5%)	(−0. 17)	(−0. 8)	(−)	Surface haze, cracks
1%	+0. 05	−4. 6	990	No change
Milk of lime 10%	+0. 04	−5. 1	970	No change
(5%)	(−0. 46)	(+2. 7)	(−)	Cracks
Organic acids				
Acetic acid 100%	+3. 25	−7. 3	660	Turbid
70%	+0. 15	−2. 0	990	No change
(70%)	(+0. 86)	(−40. 5)	(−)	Turbid
50%	+0. 14	−4. 7	970	No change
(50%)	(+0. 64)	(−33. 5)	(−)	Turbid
10%	+0. 21	−4. 1	950	No change
(10%)	(+0. 48)	(−44. 1)	(−)	Cracks
Formic acid 97%	+1. 92	−12. 7	970	No change
70%	+0. 68	−6. 4	920	No change
(70%)	(+1. 91)	(−77. 5)	(−)	Cracks
(40%)	(+0. 86)	(−75. 7)	(−)	Cracks
10%	+0. 28	−4. 7	950	No change
Maleic acid 10%	+0. 07	−4. 1	920	No change
Benzoic acid 10%	+0. 21	−6. 6	990	No change
Lactic acid 10%	+0. 09	−1. 4	930	No change
(10%)	(+0. 23)	(+4. 9)	(−)	Cracks
1%	+0. 15	−4. 4	920	No change
Oxalic acid (30%)	(+0. 25)	(+2. 7)	(−)	Cracks
10%	+0. 12	−4. 1	940	No change

Picric acid 2%	+0.13	−6.7	960	No change
Petroleum components				
n−Hexane	+0.07	−5.4	930	No change
Solvent naphtha				Turbid, swells
Cyclohexane	+0.07	−4.4	920	No change
	(−)	(−)	(−)	Dissolve completely

Name of chemicals	Change in weight %	Change in tensile strength %	Impact value J／m	Change in appearance
Petroleum ether	+0.003	−2.4	950	No change
Kerosine	+0.08	−4.4	930	No change
	(−0.07)	(+0.2)	(−)	Cracks
Ligroin	+0.15	−7.1	970	No change
(B. P. above80℃)	(+0.49)	(−0.3)	(−)	No change
Benzene	−	−	−	Swell, dissolve
Toluene	−	−	−	Swell, dissolve
Spindle oil	+0.003	−5.2	930	No change
Dynamo oil	+0.003	−5.9	940	No change
	(−0.05)	(+2.0)	(−)	No change
Turbine oil	+0.003	−4.7	950	No change
Machine oil	+0.03	−0.9	940	No change
	(+0.02)	(+0.7)	(−)	No change
Refrigerator oil	+0.018	+0.8	970	No change
Marine engine oil	+0.017	−4.1	940	No change
Cylinder oil	+0.007	−2.9	960	No change
	(+0.01)	(+0.7)	(−)	No change
Heavy oil	+0.07	−1.7	940	No change
Gasoline (low aromatics)	+0.009	−1.9	920	No change
Insulating oil	(−0.02)	(+1.9)	(-)	No change
Vegetable oils				
Soy bean oil	+0.08	−5.2	930	No change
Peanut oil	+0.07	−5.9	930	No change
	(−0.13)	(+2.5)	(−)	No change
Caster oil	+0.08	−4.4	940	No change
Organic solvents				
Methanol	+1.47	−21.5	1000	Cracks on surface
Ethanol 100%	+0.50	−11.2	960	No change
(100%)	(+3.41)	(−67.2)	(−)	Turbid
(50%)	(+1.18)	(+1.9)	(−)	Cracks
Isopropyl alcohol	(+1.39)	(−1.0)	(−)	No change
n−Butyl alcohol	+0.12	−6.9	930	No change
	(+1.86)	(−27.5)	(−)	Whitens to translucent
n−Amyl alcohol	(+2.69)	(−26.0)	(−)	Whitens to translucent
n−Octyl alcohol	(+0.12)	(+8.1)	(−)	No change
Ethylene glycol	−0.06	−7.6	910	No change
	(+0.04)	(+1.69)	(−)	No change

Glycerine	−0. 07	−6. 9	960	No change
	(+0. 06)	(+0. 5)	(−)	No change
Ethyl ether	+15. 4	−55. 7	1000	Milky white
Acetone	−	−	−	Turbid, crumbles

Name of chemicals	Change in weight %	Change in tensile strength %	Impact value J／m	Change in appearance
Methyl ethylketone				Turbid, crumbles
Ethyl acetate				Turbid, swells
Carbon tetrachloride	+7. 9	−9. 6	960	Turbid
Carbon disulfide	+2. 0	−5. 4	930	Turbid
Triethanol amine	−0. 21	−3. 6	910	Cracks on surface
Terpene oil	−0. 02	−3. 7		No change
	(+1. 69)	(+2. 0)	(−)	Translucent turbid
Camphor oil	−0. 01	−4. 3	960	No change
	(+1. 53)	(+0. 2)	(−)	Translucent turbid
Others				
Toilet soap 3%	+0. 07	−5. 2	960	No change
Neutral soap 3%	+0. 07	−4. 9	960	No change
	(+0. 25)	(+2. 7)	(−)	Cracks
Bleaching powder 2. 5%	+0. 05	−5. 4	970	No change
Hydrogen peroxide 70%	+0. 34	−3. 9	820	Light yellow, tanslucent
30%	+0. 15	−0. 7	880	Light yellow
Formalin 30%	+0. 17	−4. 2	910	No change
	(+0. 83)	(+4. 9)	(−)	Cracks
Black tea	(+0. 27)	(+2. 0)	(−)	Cracks
Chlorine	+1. 5	−0. 2	910	Discolor to yellow

7. Optical Properties

7・1 Optical Constants and Light Transmittance

The refractive index of Iupilon / NOVAREX at normal temperature is

$$n_D\ 25^{\circ}C = 1,585$$

The temperature characteristic is as shown in Fig. 4・1・1—1. The refractive index of other resins was shown in Table 7・1—1.

Table 7・1—1 Refractive index of various plastics

Polymers	n_D 25	Polymers	n_D 25	Polymers	n_D 25
		Polymethyl・methacrylate	1.490—1.500		
Polystyrene	1.590—1.600	(PMMA)	1. 570	PETP	1. 655
Polymethylstyrene	1.560—1.580	Acrylonitrile・		66 Nylon	1. 530
Polyvinyl acetate	1.450—1.470	Styrene（AS		Polyacetal	1. 480
		Polytetrafluoroethylene	1. 350		
Polyvinyl chloride	1. 540	Polutrifluoro ethylene monochloride	1. 430	Phenoxy resin	1. 598
Polyvinylidene chloride	1.600—1.630	Low density polyethylene	1. 510	Polysulphone	1. 633
Cellulose acetate	1.490—1.500	High density polyethylene	1. 540	SBR	1.520—1.550
Propionic acid Cellulose	1.460—1.490	Polypropylene	1. 490	TPX	1. 465
Nitrocellulose	1.460—1.510	Polybutyrene	1. 500	Epoxy resin	1.550—1.610

The relation between light transmittance and thickness of Iupilon / NOVAREX is shown in Fig. 7・1—1.
The wavelength characteristic is shown in Fig. 7・1—2. The light transmittance wavelength characteristics of polycarbonate and other transparent materials are shown in Fig. 7・1—3.

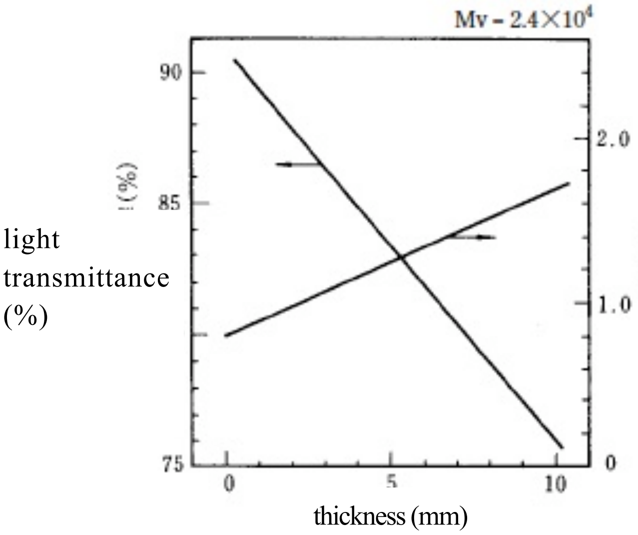


Fig. 7・1—1 Relation between light transmittancee and thickness of Iupilon /

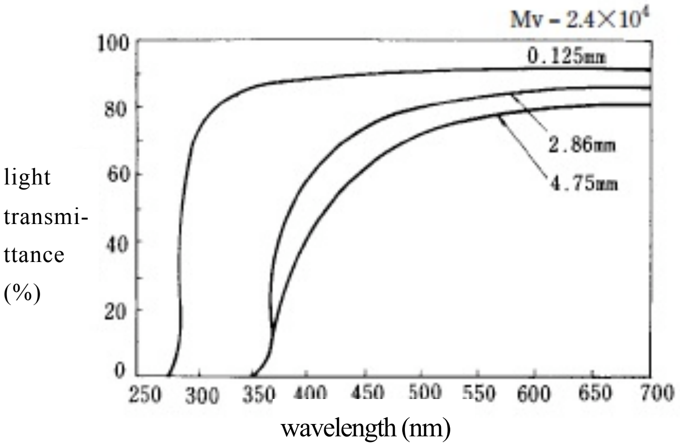


Fig. 7・1—2 Light transmittance of Iupilon / NOVAREX

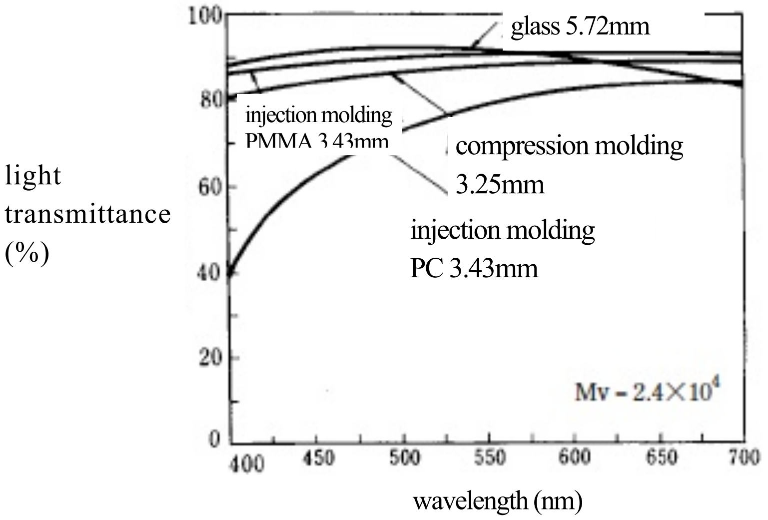


Fig. 7・1—3　Comparison of light transmittance

The change in light transmittance and haze in case of adding filling agent or pigment to Iupilon / NOVAREX is shown in Fig. 7・1—4. The appearance of the change in these characters depends on the characteristics of the additives.

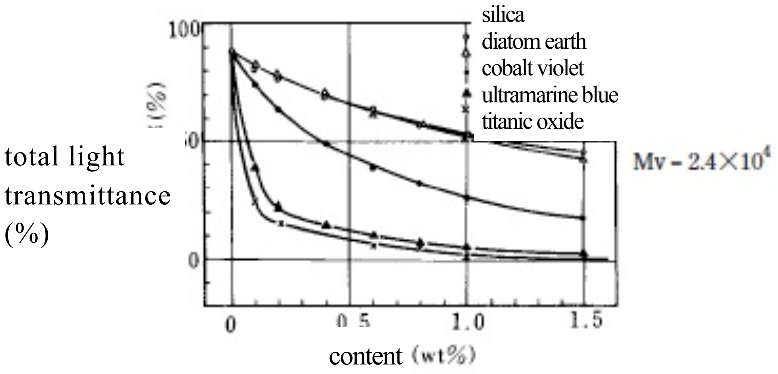


Fig. 7・1—4　Content of filling agent and light transmittance (sample thickness 3mm)

Also, the ultraviolet absorption spectrum and infrared absorption spectrum of Iupilon / NOVAREX are shown in Fig. 7・1—5, 7・1—6 and 7・1—7.

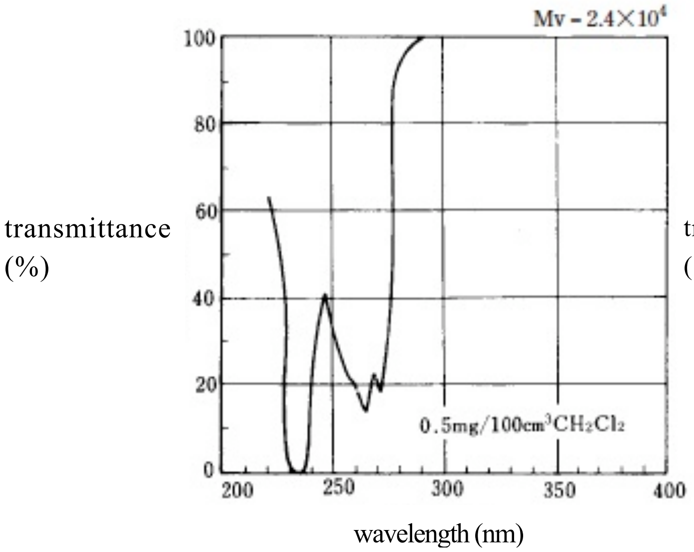


Fig. 7・1—5 Ultraviolet absorption spectrum of Iupilon / NOVAREX

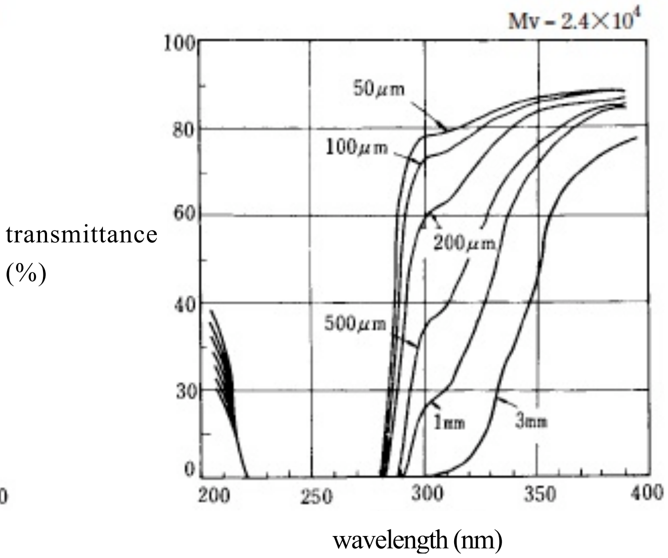


Fig. 7・1—6 Ultraviolet transmittance and thickness of Iupilon / NOVAREX

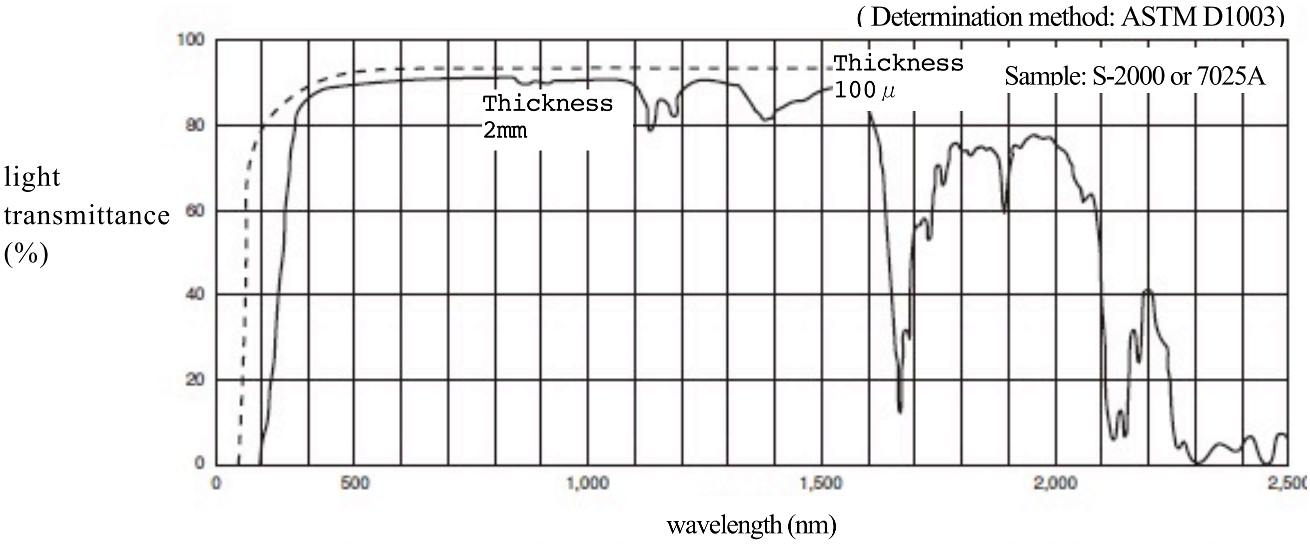


Fig. 7・1―7 Ultraviolet, visible and near-infrared absorption spectrum of Iupilon / NOVAREX

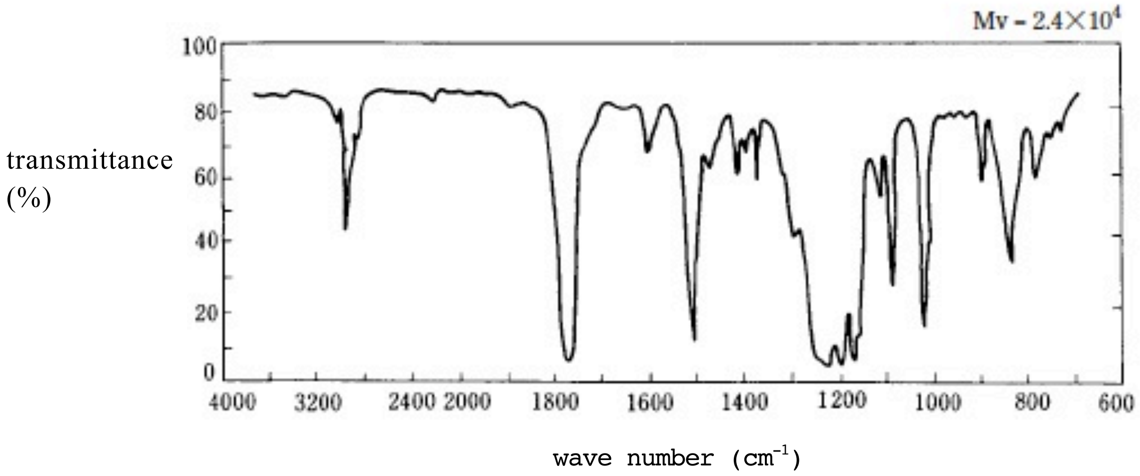


Fig. 7・1―8 Infrared absorption spectrum of Iupilon / NOVAREX

7・2 Weathering (Light) Resistance

As shown in Fig. 7・1―5, Iupilon / NOVAREX has excellent ultraviolet absorption capacity for the short wavelength ultraviolet and excellent durability to sun light and ultraviolet ray by protecting activity as ultraviolet absorber of polymer itself. However, when exposed to strong ultraviolet ray for a long time, degradation of Iupilon / NOVAREX progresses gradually and the particular degradation phenomenon is observed.

The natural degradation of Iupilon / NOVAREX begins by the photo-oxidation reaction based on ultraviolet ray near the wavelength of 290nm. The most remarkable phenomenon is the change of the surface layer resulted in various changes of chemical structure such as the formation of cross linkage and gel, decrease in molecular weight by discoloring to yellow and break in the main chain, the mechanical strength and flexibility are reduced and finally cracks occur.

The change in ultraviolet transmittance of Iupilon / NOVAREX that irradiated by ultraviolet ray and outdoor exposure is shown in Fig. 7・2―1 and 7・2―2. The change when irradiated in solution and the change in discoloring to yellow by outdoor exposure are shown in Fig. 7・2―3 and 7・2―4, respectively.

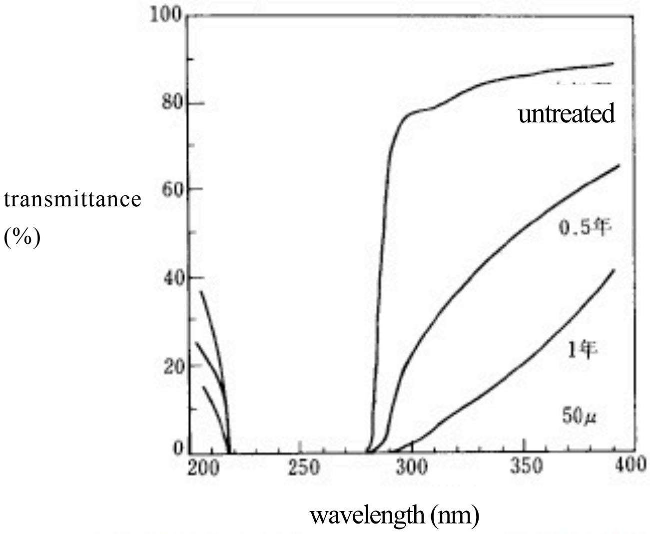


Fig. 7・2－1　Change in ultraviolet transmittance by outdoor exposure

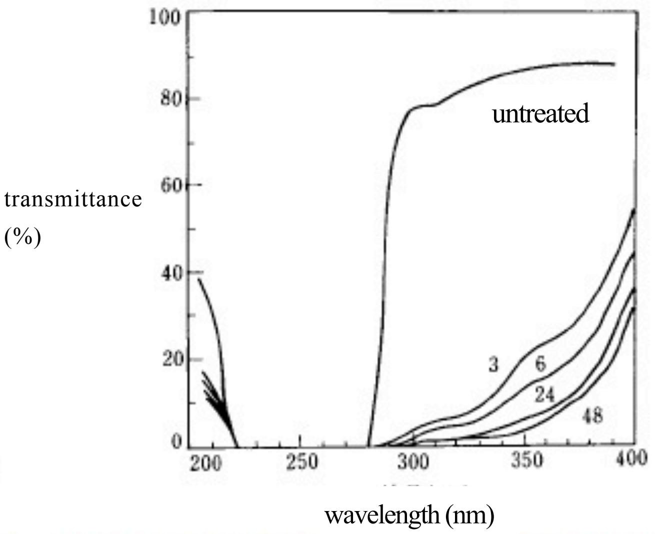


Fig. 7・2－2 Change in ultraviolet transmittance by ultraviolet radiation (time)

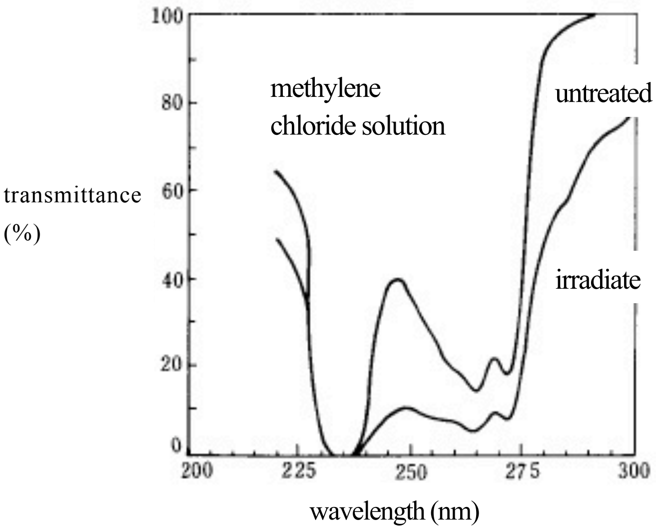


Fig. 7・2－3　Change in ultraviolet transmittance by ultraviolet radiation

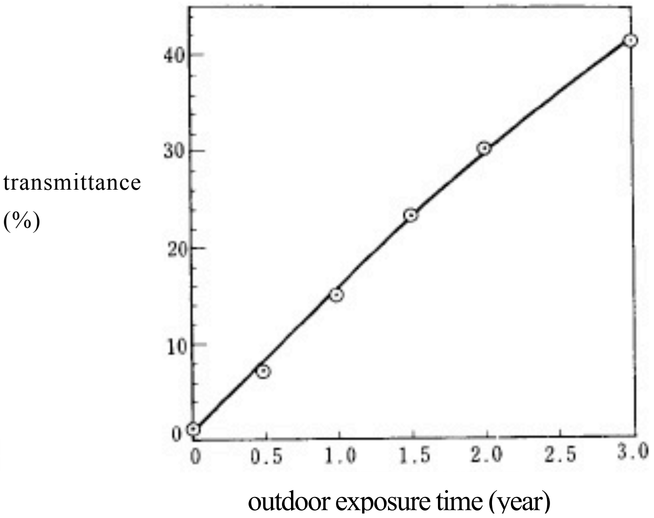
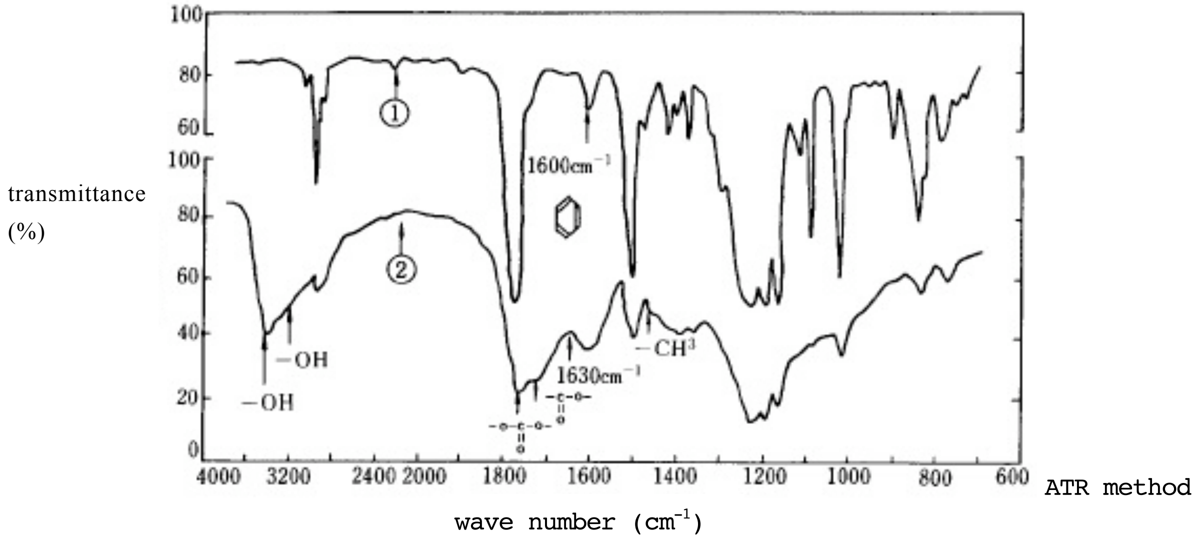


Fig. 7・2－4　Change in discoloring to yellow by outdoor exposure

The change in infrared absorption spectrum by exposure to ultraviolet ray was shown in Fig. 7・2－5 and 7・2－6, respectively. As shown in Fig. 7・2－5, the increase in $-OH$ group, decrease of $-CH_3$ group, $>C=0$ group are observed, and the absorption of the ester and benzophenone groups appears at $1720cm^{-1}$, $1630cm^{-1}$.

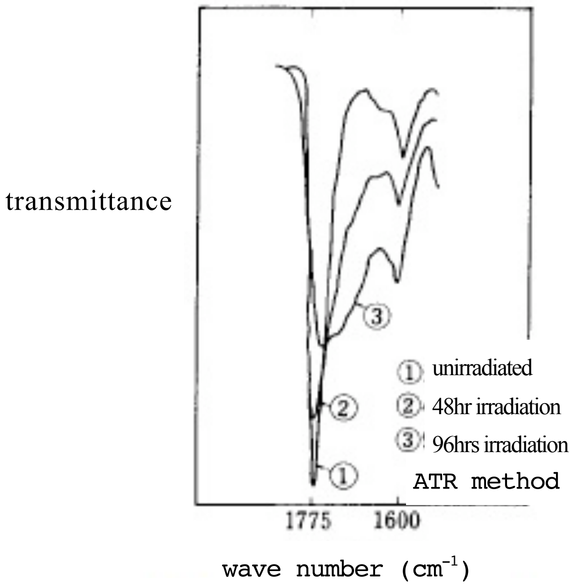
Fig. 7・2－6 shows the multi reflection infrared-absorption spectrum which indicated the chemical structure change at the surface layer after the irradiation. The change in the absorption strength at $1775cm^{-1}$ is shown clearly, and it is a very considerable change. The change of this carbonic acid group was shown in Fig. 7・2－7.

The surface layer that caused the degradation is insoluble in methylene chloride, and it can be considered that obviously, the branch and cross-linking reaction take place. The formation of this gel layer is as shown in Fig. 7・2－8.



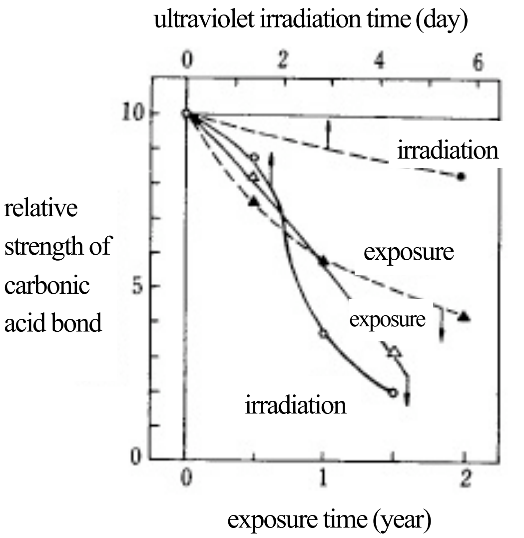
① Unirradiated（Iupilon / NOVAREX） ② Irradiated（Iupilon / NOVAREX）Insoluble matter in methylene chloride

Fig. 7・2－5 Change in infrared absorption spectrum by exposure to ultraviolet ray



1775cm -1 : Carbonic acid bond（>C=0）
1600cm -1 : Double bond of benzene ringg

Fig. 7・2－6 Change in infrared absorption spectrum by exposure to ultraviolet ray (change in carbonic acid bond)



···▲···●···sample back side

Fig. 7・2－7 Change in carbonic acid bond

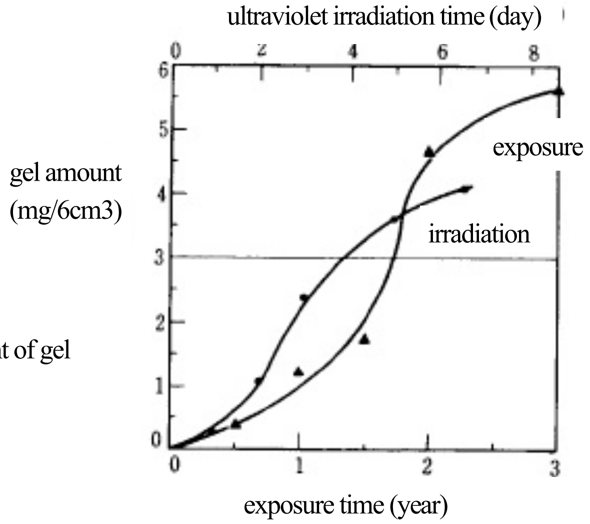


Fig. 7・2－8 Formation amount of gel

The results of outdoor exposure test and weather meter of Iupilon / NOVAREX are shown in Fig. 7・2−9, 10, 11, 12 and 13.

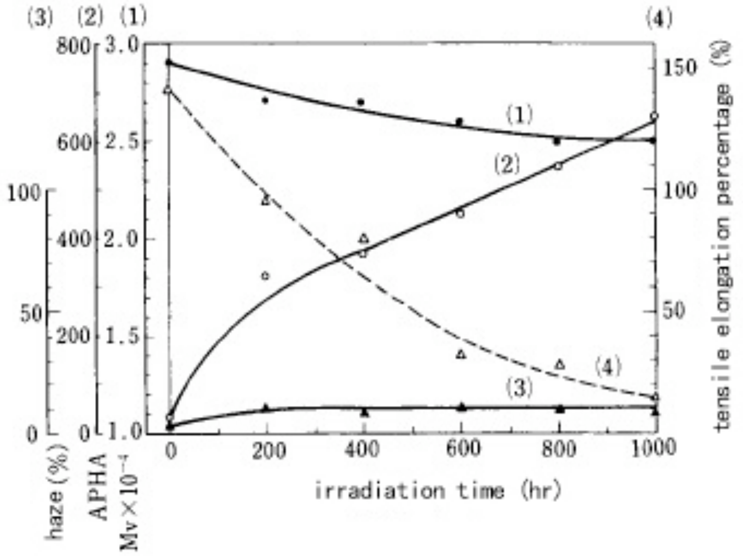


Fig. 7・2−9 Degradation by sunshine type weather meter (thickness 200μm)

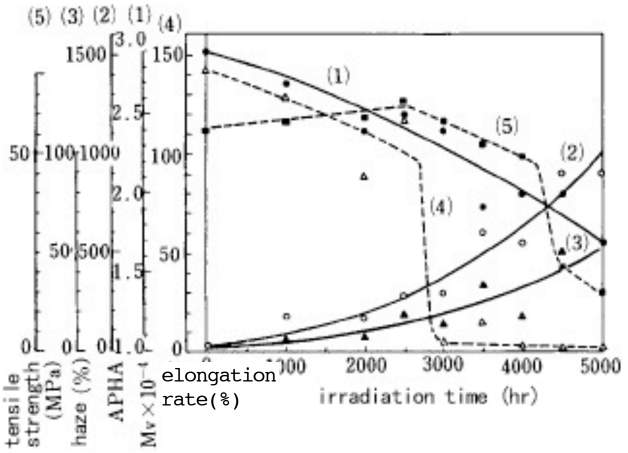


Fig. 7・2−10 Degradation by weather meter (thickness 200μm)

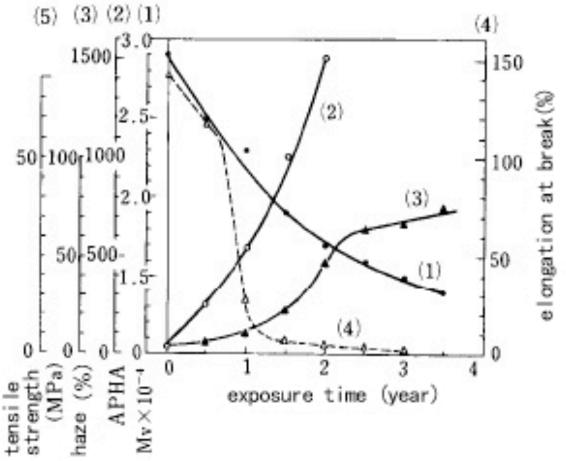


Fig. 7・2−11 Degradation by outdoor exposure test (thickness 200μm)

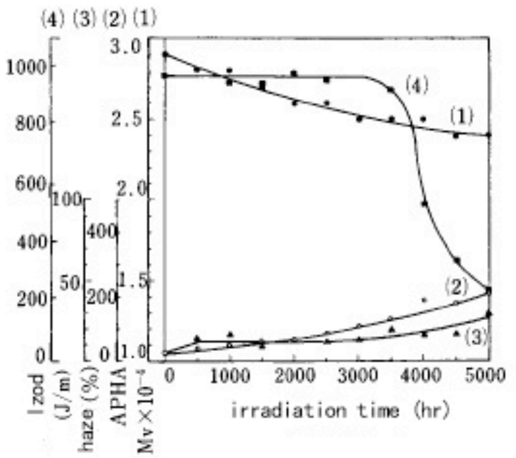


Fig. 7・2−12 Degradation by weather meter (thickness 3.2mm)

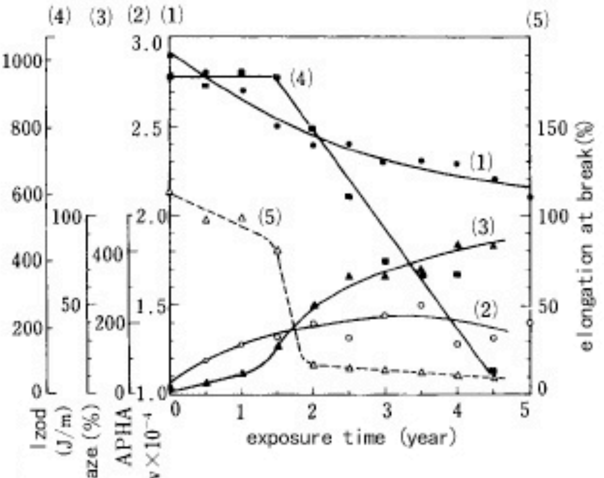


Fig.7・2−13 Degradation by outdoor exposure (thickness 3.2mm)

The above results have the distinctive changes as follows:

(1) A remarkable difference in discoloring to yellow by the sample thickness is observed but the difference in haze is hardly detected.

(2) Though the molecular weight is high enough, the brittleness is shown by tensile test.

Such a change is big near the surface layer, but conversely it means that the inside is protected by the surface layer. Therefore, it can be considered that the relationship between the degradation and sample thickness is significant. Fig. 7・2—14 (change of carbonic acid group 1770cm^{-1} of infrared spectrum), Fig. 7・2—15 (APHA), Fig. 7・2—16 (〔η〕), Fig. 7・2—17 (Mv) and Fig. 7・2—18 (Mv) are the results which show the influence by thickness. As for the method of improving the weather resistance of Iupilon / NOVAREX, the addition of ultraviolet absorber and stabilizer or inorganic filling agent can be considered as the most usual method.

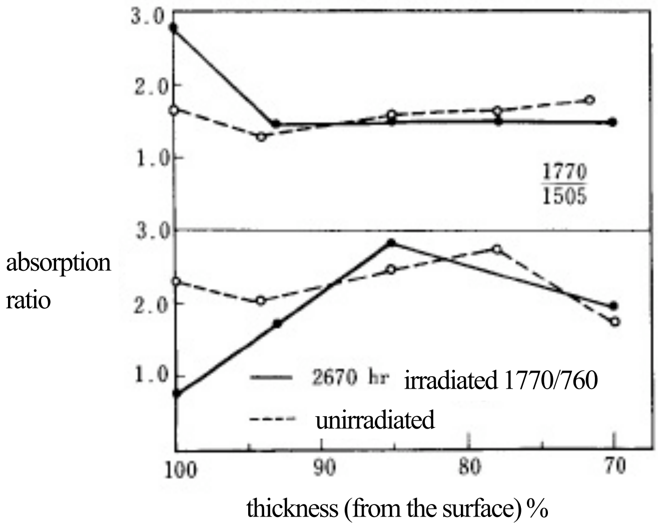


Fig. 7・2－14 Change status of carbonic acid group by thickness

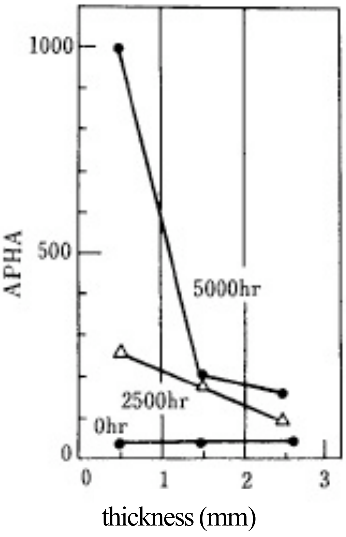


Fig. 7・2－15 Difference in APHAby weather meter

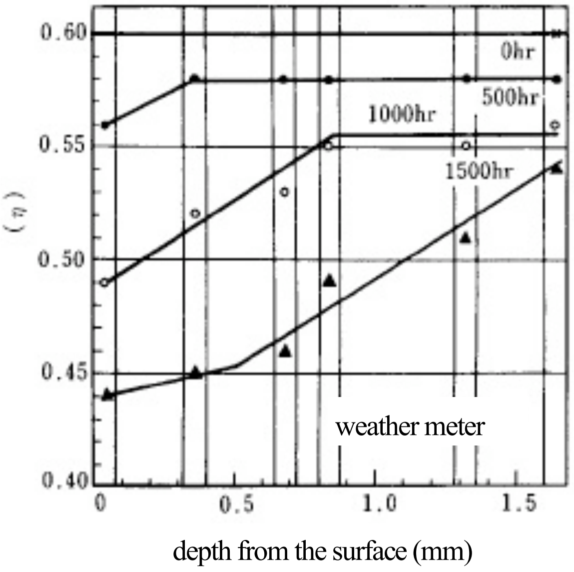


Fig.7・2－16 Difference in molecular weight decrease by thickness

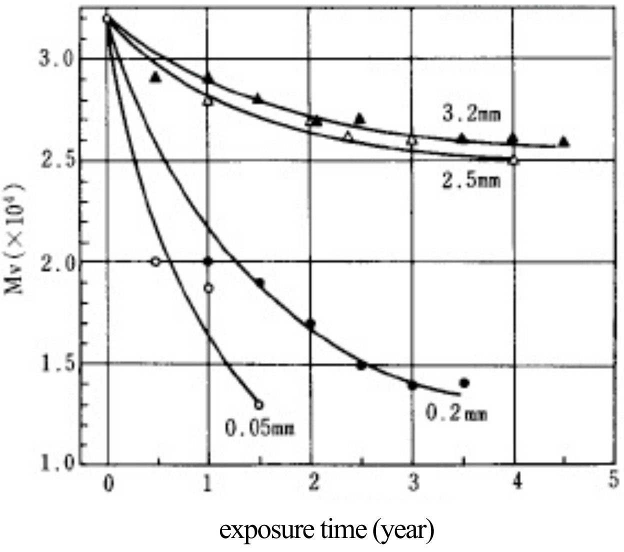


Fig. 7・2－17 Relation between molecular weight decrease and sample thickness at exposure degradation

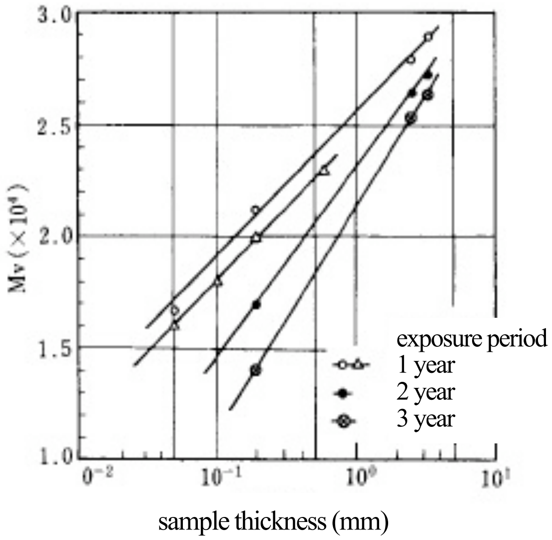


Fig. 7・2－18　Relation between molecular weight (Mv) decrease and sample thickness

Fig. 7・2－19 (yellowing degree), Fig. 7・2－20 (Mv), Fig. 7・2－21 (tensile break elongation rate), Fig. 7・2－22 (tensile strength), Fig. 7・2－23 (flexural strength), Fig. 7・2－24 (transparency and haze) and Fig. 7・2－25 (APHA) show the effects of UV absorber addition.

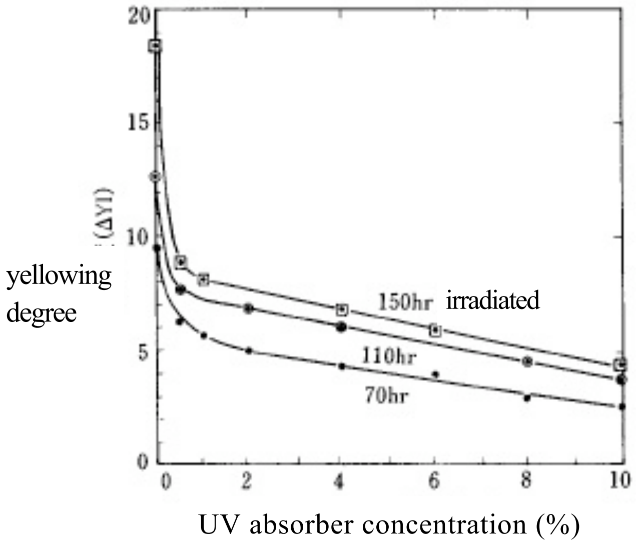


Fig. 7・2－19 Relation between UV absorber concentration and yellowing degree by UV irradiation

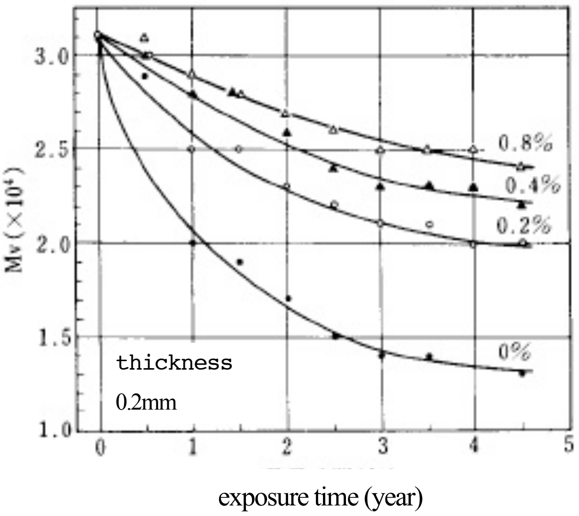


Fig. 7・2－20 UV absorbent content and molecular weight decrease by exposure test

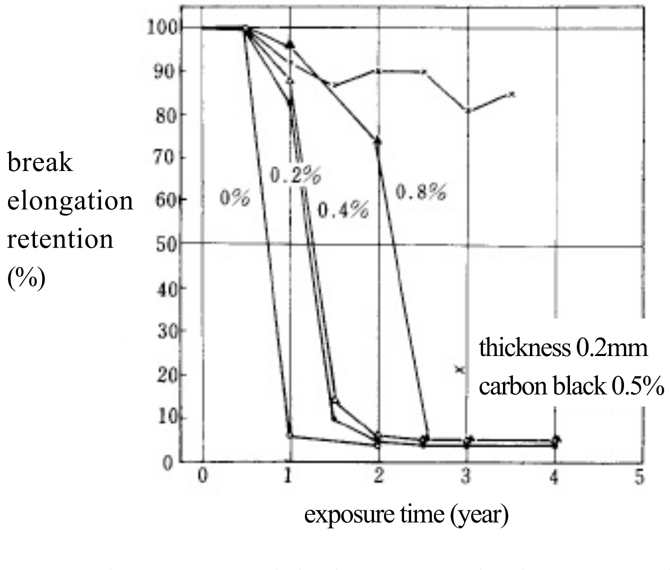


Fig. 7・2－21 Relation between UV absorber content and tensile break elongation rate decrease by exposure test

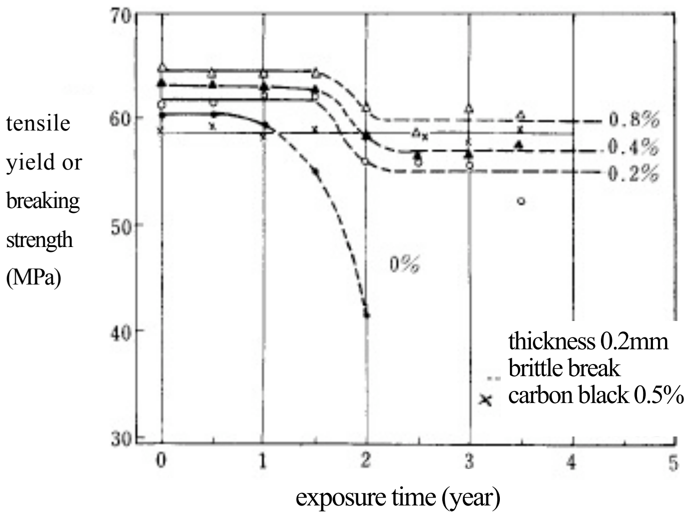


Fig. 7・2－22 Relation between UV absorber and tensile strength change by exposure test

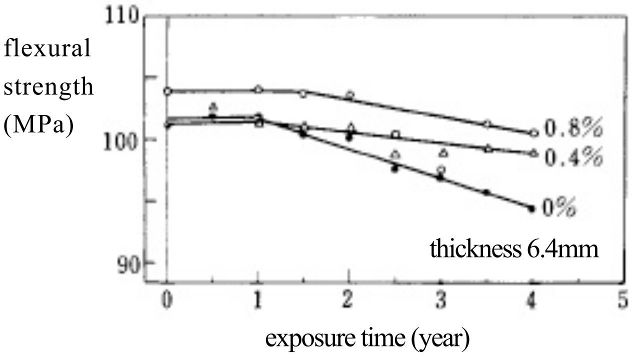


Fig. 7・2—23 Change in flexural strength by exposure test

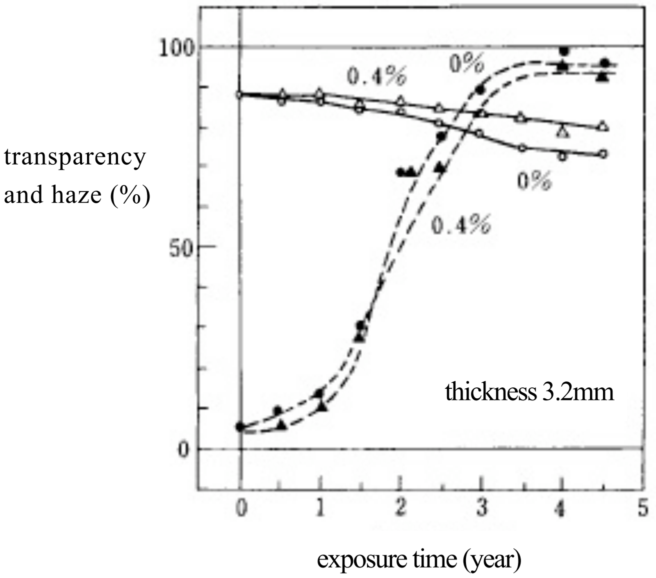


Fig. 7・2—24 Change in transparency and haze by exposure

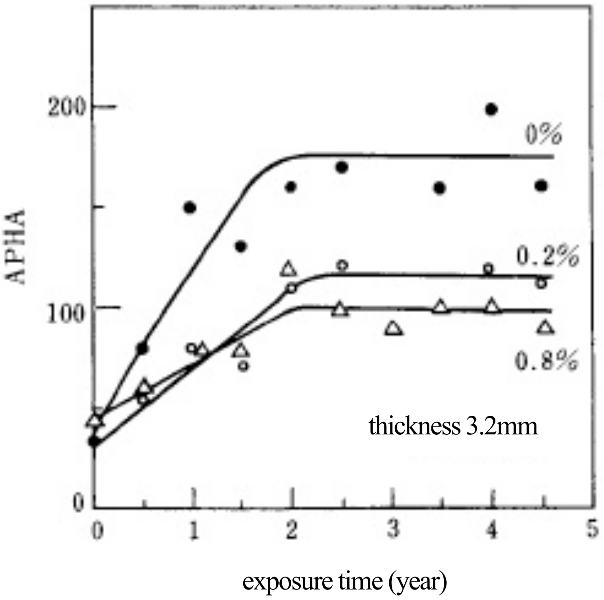
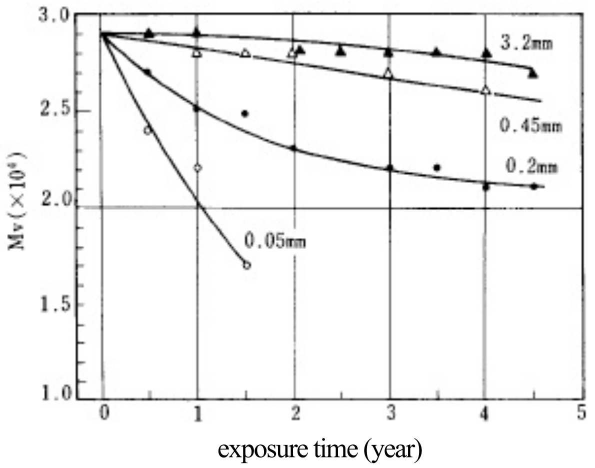


Fig. 7・2—25 Yellowed property by exposure

The addition of ultraviolet absorber shows the effect to each physical property, but it does not necessarily say that it is enough. As mentioned before, because polycarbonate is considerably influenced by the thickness, it is necessary to consider the stabilized sample.

Fig. 7・2—26 (Mv) , Fig. 7・2—27 (tensile property), Fig. 7・2—28 (break elongation) and Fig. 7・2—29 (APHA) showed the influence of thickness on the weathering resistance of the sample containing 0.4% of UV absorber. If the thickness is 0.45mm, the molecular weight decrease is small, and it turns out that the breaking situation can also maintain the ductile breaking state.



Sample　Mv＝2.　9×10^4 containing 0.4% of UV absorber

Fig. 7・2－26 Influence of sample thickness on molecular weight (Mv) decrease

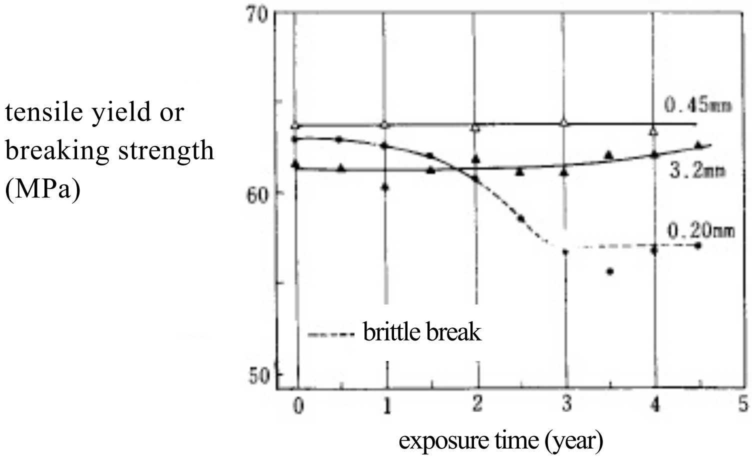
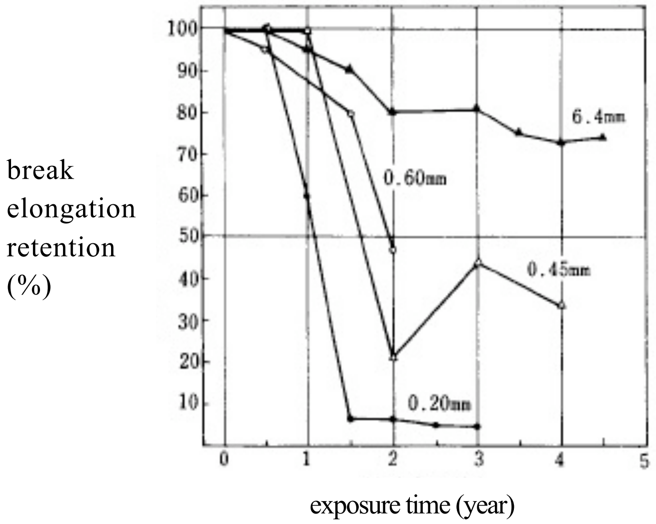


Fig. 7・2－27 Relation between sample thickness and change in tensile strength



Sample: containing 0.4% of UV absorber

Fig. 7・2－28 Relation between sample thickness and break elongation decrease

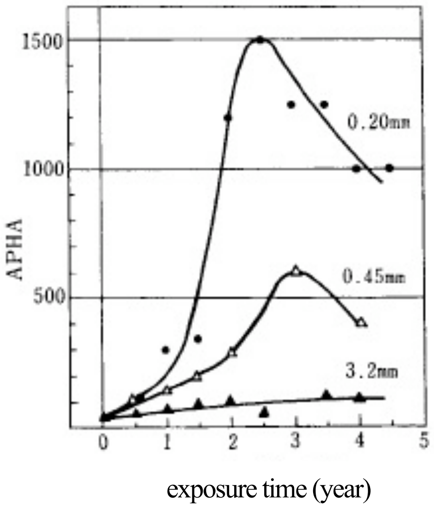


Fig. 7・2－29 Relation between sample thickness and APHA change

Next, the effect of the addition of inorganic filling agent in the improvement of the weathering resistance is also known. The typical example is carbon black, as shown in Fig. 7・2－21 and 7・2－22, the fact that it is more effective than the ultraviolet absorber in Iupilon / NOVAREX is indicated.

From this meaning, the result of examining the inorganic pigment was shown in Table 7・2－1. In addition, the result of the long-term exposure test of the sample containing titanium white was shown in Table 7・2－2.

Table 7・2－1 Influence of pigment addition in outdoor exposure test

Type of pigment	Additive amount (%)	pH	Untreated	Outdoor exposure 1 year		Thickness (μm)
			Molecular weight ($\times10^4$)	Molecular weight ($\times10^4$)	ΔE	
Blue pigment	0．2	9．4	2．8	2．1	5．6	50
Red oxide	0．2	7．6	2．8	2．1	4．9	50
Shanin green	0．2	6．5	2．8	2．1	4．3	50
Cadmium yellow M3600	0．2	7．3	2．8	2．1	2．2	50
Cadmium yellow M3200	0．2	7．2	2．8	2．1	1．8	50
Cadmium red L6600	0．2	8．2	2．8	2．2	2．6	50
Cadmium red M8300	0．2	8．2	2．8	2．1	2．7	50
Cadmium red 05700	0．2	8．1	2．8	2．6	2．9	50
Shanin blue LBGT	0．2	8．0	2．8	2．3	1．0	50
Carbon black						
Nippiru#100 (Nittetsu)	0．5	4．7	2．8	2．4	3．0	50
FB44 (Mitsubishi carbon)	0．5	7．7	2．8	2．3	3．8	50
#50 (Mitsubishi carbon)	0．5	6．0	2．8	2．3	4．5	50
#600 (Mitsubishi carbon)	0．5	7．0	2．8	2．5	5．6	50
For rubber H (〃)	0．5	7．7	2．8	2．5	2．5	50
Mark □ (Columbia)	0．5	3．0	2．8	2．4	9．0	50
#999 (Columbia)	0．5	3．9	2．8	2．3	7．0	50
Blank	0		2．8	1．8	8．2	50
Titanium white R820	0．7		2．8		13．6	200
Titanium white R101	0．7		2．8		14．4	200
Carbon black (for rubber H)	0．5		2．8		2．0	200
Carbon black (#100)	0．5		2．8	2．6	4．4	200
Blank	0		2．8	2．0	11．0	200

Table 7・2－2 Influence of UV, TiO_2 in exposure test

	Additives (%)		Change in Mv by exposure test ($\times10^4$)					Generation rate of brittle break by falling ball test (%)				
	UV	TiO_2	0 year	2years	3years	4years	5years	0 year	1 year	2 years	3 years	4 years
1	0	0	3．1	2．8	2．7	2．6	2．5	0	90	100	100	100
2	0．4	0	3．1	3．0	3．0	3．0	3．0	0	0	0	0	0
3	0	0．5	3．1	2．8	2．6	2．6	2．6	0	5	15	100	100
4	0．4	0．5	3．0	2．7	2．6	2．6	2．6	0	0	0	0	25

Sample thickness 2.5mm, UV: ultraviolet absorber
The falling ball test drops the steel ball of 3.6kg from the height of 3.85m on a hemisphere body of 146mm inside diameter and examines the breaking situation.

7・3 Degradation by Irradiation

When polycarbonate is irradiated with the electron beam, the radiation, and the X-ray etc. the degradation takes place. For example, the analysis result of gas generated when polycarbonate is irradiated with the gamma ray was shown in Table 7・3―1. From this, a large part of CO_2, CO gas generation, and some amount of CH_4, H_2 are observed. From the above results, it can be said that the degradation of polycarbonate results from the break in the main chain as the most part, and some sub-degradation as shown in the following formula.

Table 7・3―1 Gas generated by gamma-irradiation (gas generated rate %)

Irradiance level (γ)	Weight decrease (%)	CO	CO_2	H_2	CH_2	CO/CO_2
1×10^8	0. 33	79. 3	15. 8	4. 5	0. 4	0. 4
2×10^8	0. 70					1. 8
3×10^8	1. 54	61. 6	34. 4	3. 2	0. 8	
10×10^8		61. 2	31. 0	7. 0	0. 8	2. 0

If the degradation of polycarbonate by irradiation takes place by the break in the main chain, as a matter of fact, the average molecular weight decrease (Fig. 7・3―1) and the degradation of mechanical properties (Fig. 7・3―2) are observed.

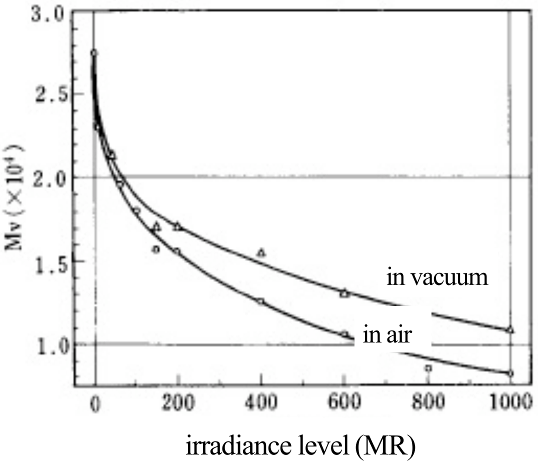


Fig. 7・3―1 Decrease in molecular weight by irradiation

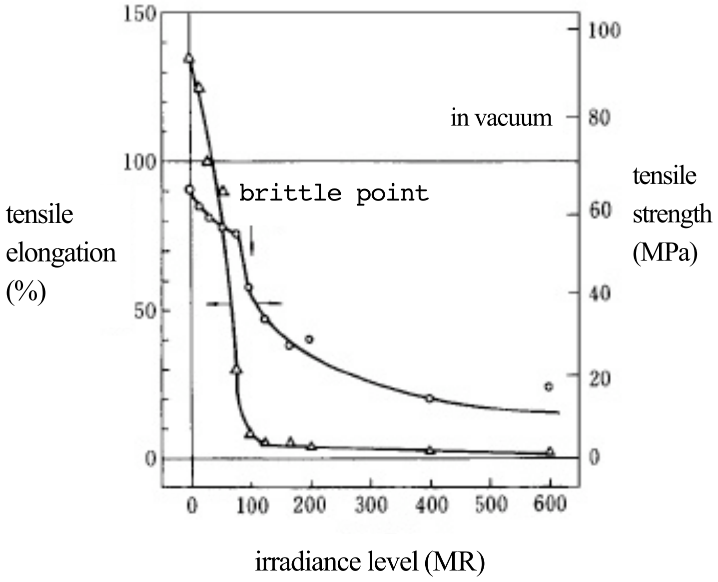


Fig. 7・3―2 Change in tensile property by irradiation

The degradation by irradiation and a comparison with other resins are shown in Table 7・3−2 and Table 7・3−3, respectively.

Table 7・3−2 Gas generated by decomposition of various resins by gamma-irradiation （μmol／g）

Polymers	CO_2	H_2	CO	Methane	Ethane	Butane	Butene	Methyl chloride	Pentene	Methanol
Polycarbonate	32．5	1．5	66．0				4．6	4．0	1．6	
Polyester 1	56．3	33．5								
Polyester 2	82．0	18．0								
High density polyethylene	3．0	92．0	5．0							
Low density polyethylene	1．0	91．0	1．0		2．0	3．5	1．5			
Polypropylene	1．0	95．0	1．0	3．0						
66 Nylon	5．0	71．0	24．0							
11 Nylon	1．0	66．0	29．0	4．0						
Chlorinated polyether	8．7	85．8					1．4	3．8	0．3	
Polyacetal	69．0	7．5		15．0						2．0

6Mrad in vacuum

Table 7・3−3 Comparison of generation amount of decomposed gas by gamma-irradiation

Order	Generation amount of gas（1）	
1	Below 1	Polyester 1，Polyester 2，Polyethylene，Polychlorotrifluoroethylene
2	1−5	Polycarbonate，66 Nylon，Polyamide11，Chlorinated polyether
3	5−10	Polyvinylidene chloride
4	10−15	Polyvinyl chloride，Polyethylene of polyester coating
5	15−20	Polyethylene，Polypropylene
6	Above 50	Polyacetal

International System of Units（SI units）

Main Unit Conversion Table

	N	dyn	kgf		
Force	1	1×10^{5}	1．01972×10^{-1}		
	1×10^{-5}	1	1．01972×10^{-6}		
	9．80665	9．80665×10^{5}	1		

	Pa	kgf/cm^{2}	atm	mmHg・Torr	
Pressure	1	1．01972×10^{-5}	9．86923×10^{-6}	7．50062×10^{-3}	
	9．80665×10^{4}	1	9．67841×10^{-1}	7．35559×10^{2}	
	1．01325×10^{5}	1．03323	1	7．60000×10^{2}	
	1．33322×10^{2}	1．35951×10^{-3}	1．31579×10^{-3}	1	

	Pa or N／m^{2}	kgf/mm^{2}	kgf/cm^{2}		
Stress	1	1．01972×10^{-7}	1．01972×10^{-5}		
	9．80665×10^{6}	1	1×10^{2}		
	9．80665×10^{4}	1×10^{-2}	1		

	J	kW・h	kgf・m	kcal	
Energy・Work・Heat	1	2．77778×10^{-7}	1．01972×10^{-1}	2．38889×10^{-4}	
	3．600×10^{6}	1	3．67098×10^{5}	8．6000×10^{2}	
	9．80665	2．72407×10^{-6}	1	2．34270×10^{-3}	
	4．18605×10^{3}	1．16279×10^{-3}	4．26858×10^{2}	1	

	W	kgf・m／S	PS	kcal／h	
Power	1	1．01972×10^{-1}	1．35962×10^{-3}	8．5985×10^{-1}	
	9．80665	1	1．33333×10^{-2}	8．43371	
	7．355×10^{2}	7．5×10	1	6．32529×10^{2}	
	1．16279	1．18572×10^{-1}	1．58095×10^{-3}	1	

	Pa・S	cP	P		
Viscosity (viscous modulus)	1	1×10^{3}	1×10		
	1×10^{-3}	1	1×10^{-2}		
	1×10^{-1}	1×10^{2}	1		

	m^{2}／S	cSt	St		
Kinetic viscosity（kinematic viscosity coefficient）	1	1×10^{6}	1×10^{4}		
	1×10^{-6}	1	1×10^{-2}		
	1×10^{-4}	1×10^{2}	1		

Heat conductivity	W／(m・K)	kcal／(h・m・℃)			
	1 1. 16279	8. 6000×10^{-1} 1			

Specific heat	J／(kg・K)	kcal／(kg・℃) cal／(g・℃)			
	1 4. 18605×10^{3}	2. 38889×10^{-4} 1			

CAUTION

●Data described in this catalog are typical examples of the measurement by our company's test method.

●The use application described in this catalog does not guarantee the application result to the said usage of this product.

●Please consider the industrial property and use conditions etc. related to the usage and application described in this catalog in your company.

●Please refer to the used material, technical information of the grade and product safety data sheet (MSDS) in the handling of this product (transportation, storage, molding, disposal etc.).

Especially, please confirm safety sufficiently when using the food container wrapping, medical parts, safety tool, and toys for infants etc.

●The chemicals (carbon black, titanium oxide, zinc oxide) that should notify in applicable laws and regulations, Item 2 of the Article 57 of the Occupational Health and Safety Law, Item 2 of the enforcement order 18, name in attached table 9 etc. may be contained in case of each grade colored article of this product. Please contact for the details.

●Because some items of the MEP products correspond to specified articles of the controlled target products under the Export Trade Control Ordinance, please contact for the details.

Please conform to the applicable laws and regulations of the Foreign Exchange and Foreign Trade Control Law etc. when conducting the export and sale of the MEP product and the product that included it.

●The deterioration of some articles in this product may occur due to the residual fumigant which is used for the fumigation treatment of the wooden pallet.

Please refrain from carrying out the fumigation treatment by loading the corresponding product on the wooden pallet or loading on the wooden pallet that the fumigation was treated.

●There is a possibility that harmful gas and fume are generated by the heat decomposition of the resin at the time of molding and cleaning the tack.

Please install the ventilator for the local or the whole ventilation.

●When the product which added fluorocarbon resin is heated above 250℃, the poisonous gas may be generated due to the decomposition of fluorocarbon resin. Therefore, the ventilation of work environment should be done sufficiently. Also, please do not burn this product when disposing it but carry out the landfill instead.

※Please acknowledge that the contents of this catalog might be changed without notice for the revision.